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No. 1, JANUARY 1979

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NUMERICAL ANALYSIS OF METEOROLOGICAL FIELDS WITH USE OF SATELLITE DATA

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 5-10

[Article by Candidate of Physical and Mathematical Sciences S. I. Gubanova, Professor S. A. Mashkovich and Ye. L. Metelitsa, USSR Hydrometeorological Scientific Research Center, submitted for publication 22 May 1978]

Abstract: A study was made of the effect of joint use of aerological and satellite data in a four-dimensional analysis model [9]. The model is based on spatial-temporal optimum interpolation. The authors give the quantitative characteristics of the contribution of satellite measurements in four-dimensional analysis for the northern hemisphere in specific situations. There is an analysis of the influence of asynchronicity of observations. Evaluations of a refinement of analysis of OT_{1000}^{500} charts are given.

[Text] The problem of initial information is one of the most important in the numerical forecasting problem. There are different approaches to solution of this problem. The most natural way to solve it is to obtain additional information on the state of the atmosphere obtained using new observational means, such as the method of remote sounding of the atmosphere from artificial earth satellites. The use of satellite data in a numerical analysis of meteorological fields is associated with solution of a number of problems. One of them is computation of the vertical distribution of temperature, relative topography and humidity on the basis of radiation measurements from a satellite. Another equally important problem is the development of effective methods for taking into account data on these vertical profiles in numerical analysis. This problem is the subject of this article.

Data on the vertical distribution of temperature and relative topography, obtained on the basis of such sounding, constitute that form of information which, it would seem, can be used directly in numerical analysis. In actuality, however, definite difficulties arise here. In contrast to traditional aerological measurements, as a rule rigorously tied in to definite geographical points and observation times, satellite data can be arbitrarily distributed in time and space. Therefore, allowance for them involves a changeover from ordinary spatial (three-dimensional) objective analysis to four-dimensional analysis. It is important that the errors in satellite information are considerably greater than in aerological data and also that these errors may be correlated (for example, see [10]). In this connection there is no clear idea as to whether the mentioned satellite data are adequately reliable and to what extent they can be used effectively in numerical analysis and forecasting: opinions on this score are extremely contradictory [2, 11-13].

Below we present the results of numerical experiments on the joint use of aerological and satellite data in numerical objective analysis; an evaluation is made of the contribution of satellite information to the results of the analysis and an attempt is made to clarify whether this contribution gives a positive effect.

As was already mentioned above, reference is not to computation of vertical distributions on the basis of satellite radiation measurements, but on the use of already reconstructed vertical profiles of meteorological elements. Specifically, we were concerned with the problem of assimilation of satellite data on the relative topography of the isobaric surfaces. The corresponding information at the present time is being disseminated through the WMO global telecommunications system in the form of SATEM summaries (earlier SIRS summaries were transmitted).

The data assimilation method is based on spatial-temporal optimum interpolation. The effectiveness of use of this approach to solution of the four-dimensional analysis problem was demonstrated in [8]. Different aspects of optimum assimilation of various kinds of information were discussed in [3, 6, 7].

The numerical experiments were carried out on the basis of the four-dimensional analysis method and model developed at the USSR Hydrometeorological Center. This model is based on the spatial-temporal optimum interpolation method. It ensures joint processing of data obtained using different observation systems and having different levels of errors and it takes the correlation of measurement errors into account. More detailed information on the four-dimensional analysis model can be found in [9].

The computations were made both for cases when only aerological data were used (variant A) and for cases of joint use of aerological and satellite measurements (variant AS). In each case use was made of aerological information for one observation time and satellite measurements made not more than 12 hours from this time. Satellite information was taken from SIRS summaries received at the USSR Hydrometeorological Center. As is well known, this information was received only for ocean areas. The number of satellite sounding points in the northern hemisphere for a 24-hour interval averaged about 230 and varied in the range from 190 to 336. The number of aerological telegrams for one observation time, used in the computations, averaged about 440 and varied from 411 to 680. In the computations it was assumed that the mean relative square errors in aerological and satellite data on the relative geopotential H_{1000}^{500} are equal to 0.02 and 0.10 respectively. This means that in the middle troposphere of the temperate latitudes the error is about 2 and 5 dam. It was also assumed that the errors in satellite information were correlated and horizontal correlation is described by the formula

$$\nu(r) = \nu_0^{r/r_0}.$$

In the analysis we used the values $\nu_0 = 0.7$; $r_0 = 200$ km.

The analysis was made for a regular geographic grid with 5° intervals along the meridian and 10° intervals along the parallel (a total of 648 points on the map of the northern hemisphere). The results of the analysis of the relative topography H_{1000}^{500} presented below were obtained using data for the period from 26 through 29 April 1977, 13 and 14 January 1977, 23 June 1974.

For evaluating the differences between the two fields f_1 and f_2 below we use the values

$$\delta = |f_1(\Theta_i, \lambda_j) - f_2(\Theta_i, \lambda_j)|;$$

$$d^2(f_1, f_2) = \frac{1}{2\pi} \int_0^{2\pi} \int_0^{\pi/2} (f_1 - f_2)^2 \sin\Theta \, d\Theta \, d\lambda.$$

The d^2 value is the mean square discrepancy between the fields of the meteorological element, computed for the hemisphere. If the field of the meteorological element is approximated by a series in spherical functions

$$f_k = \sum_m \sum_n f_{k,n}^m e^{im\lambda} P_n^m(\Theta); \; f_{k,n}^m = A_{k,n}^m + iB_{k,n}^m,$$

then the expressions for d^2 can be written in the form

$$d^2 = \sum_m d_m^2;$$

$$d_m^2 = \frac{1}{2\pi} \sum_n [(A_{1,n}^m - A_{2,n}^m)^2 + (B_{1,n}^m - B_{2,n}^m)^2] \, r_m; \; r_m = \begin{cases} 1 \text{ when } m = 0 \\ 2 \text{ when } m \neq 0. \end{cases}$$

This value is computed both for the entire considered wave spectrum and for its different parts.

Now we will proceed to the results of computations. First we will evaluate those changes which occurred in the analyzed fields as a result of taking satellite information into account. As demonstrated by computations, the influence of satellite data was manifested at approximately 40% of all the points in a regular grid (the average number of such points of intersection was 270, the minimum was 260, the maximum was 285).

Now we will discuss quantitative estimates of the contribution of satellite data to analysis of OT_{1000}^{500} charts. For this purpose we will compare the results of computations in variants A and AS. As a quantitative characteristic we will cite the number of points of a regular grid with different values of the discrepancies δ. If this number of points is determined in percent of the total number of points at which the influence of satellite data was manifested, we obtain the following data:

Difference (δ) in analytical results in variants A and AS, dam	2	2-4	4-6	6-8	8
Number of points, %	40	22	14	8	16

The results of comparisons show that at almost 40% of the points allowance for satellite data led to changes of 4 dam or more, the mean change was 4.6 dam, the maximum change was 35.6 dam. Thus, their quantitative contribution is extremely significant. This same fact is indicated by the spectral evaluation (d^2) of the differences between the A and AS analyses, computed for the hemisphere:

Wave range, m	0	1-3	4-6	7-9	10-12	0-12
d^2, dam^2	1.4	2.8	1.1	0.4	0.2	5.9

The discrepancy for the entire considered part of the spectrum (max m = 12) was 5.9 dam^2; the maximum differences are observed in the zonal component m = 0) and the longest waves ($m \leqslant 4$).

An interesting problem is the role of asynchronicity of observations. For solving this problem for variant AS we carried out computations with and without allowance for the differences in observation times, the results of which demonstrated the following:

Difference (δ) in results of analysis of OT_{1000}^{500} with and without allowance for asynchronicity of observations, dam	0-1	1-2	2-4	4-6	6-8	8
Number of points, %	56	19	13	6	2	4

It can be seen that due to nonallowance for differences in observation times in 25% of the cases discrepancies (δ) arise which are more than 2 dam, in 12% of the cases these discrepancies exceed 4 dam, the mean discrepancy is 1.28 dam, the maximum discrepancy is 19.6 dam. Thus, even in a time interval less than 12 hours one must not neglect the differences in observation times.

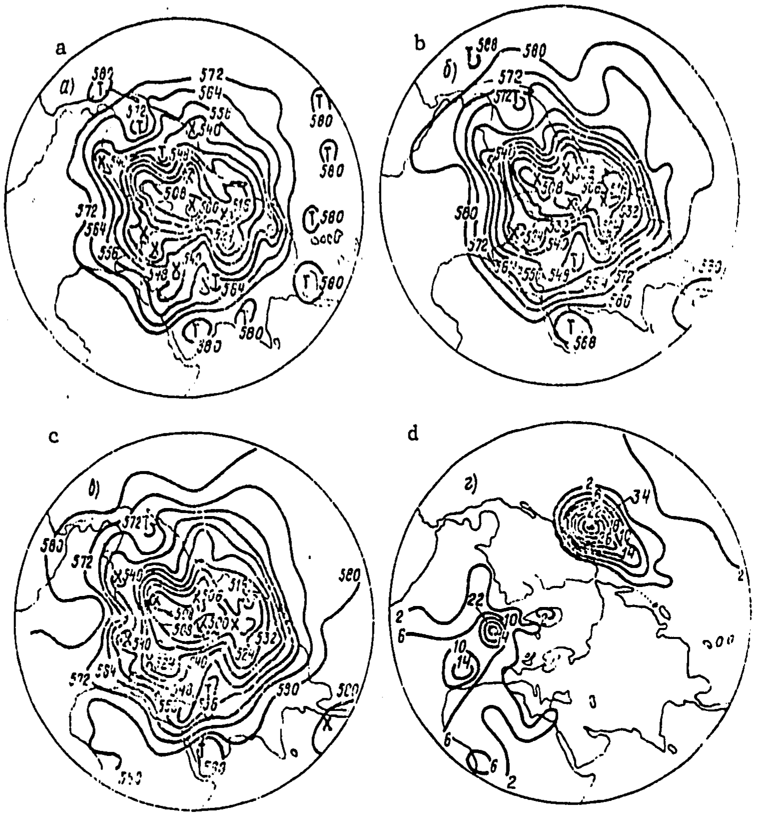

Fig. 1. Example of analysis of OT$^{500}_{1000}$ charts for 0000 hours on 28 April 1977. a) chart analyzed by weatherman; b) numerical analysis based on aerological data (variant A); c) numerical analysis using aerological and satellite data (variant AS); d) map of differences in numerical analyses with and without use of satellite data.

Table 1

Comparison of Numerical Analyses of OT$^{500}_{1000}$ Charts With Synoptic Analysis

Вариант 1	Число точек (%) с δ (дам) в пределах 2				δ среднее, дам 3
	<2	2—4	4—6	>6	
A	31,6	23,0	14,8	30,6	4,72
AS АС	37,3	23,9	15,0	23,8	4,07

KEY:
1. Variant
2. Number of points (%) with δ (dam) in range
3. Mean δ, dam

Table 2

Spectral Comparison of Numerical Analyses of OT_{1000}^{500} Charts With a Synoptic Analysis

Вариант 1	Значения d^2 (дам²) для диапазонов волновых чисел m 2					
	0	1–3	4–6	7–9	10–12	0–12
A	6,4	4,3	1,7	1,2	0,4	14,0
AS AC	3,8	3,7	1,4	1,1	0,6	10,5

KEY:

1. Variant
2. Values d^2 (dam²) for ranges of wave numbers m

Table 3

Kinetic Energy for Different Variants of Analysis (in Arbitrary Units)

Вариант 1	Диапазоны волновых чисел m 2		
	0	1–12	0–12
A	158	201	359
AS AC	172	231	403
Син 3	185	235	420

KEY:

1. Variant
2. Ranges of wave numbers
3. Syn

The presented data indicate that allowance for satellite information substantially changes the OT_{1000}^{500} charts. However, it is important to evaluate whether in actuality in this case there is an improvement in the quality of the analysis.

It is difficult to give an answer to this question: there is no standard which should be used in a comparison of the results of numerical analysis. For that reason it is necessary to seek indirect ways for evaluating the effectiveness of this information.

One of these ways is a computation of the a priori theoretical error in optimum interpolation. For such computations it is necessary to know the geographical distribution of sounding points, the levels of errors in measurements by different observation systems and the corresponding correlation functions. Computations of this type were cited in [6]. Without dwelling on these results in detail, we mention only that allowance for satellite data reduces the relative square error in optimum interpolation from 0.34 to

0.18 in the northern hemisphere and from 0.70 to 0.30 in the southern hemisphere.

Another approach is based on the arbitrary choice of a standard for comparison. For example, as a standard we can elect that variant of analysis which is assumed to be most reliable. As such a standard we used a careful synoptic analysis of the OT_{1000}^{500} charts for the northern hemisphere carried out at the USSR Hydrometeorological Center. Tables 1-3 give the results of a comparison of numerical analyses (variants A and AS) with a synoptic analysis (variant Syn). Table 1 shows the number of points (%) for different gradations of the discrepancies (δ) between the analyses. The comparison was made for the entire northern hemisphere. It can be seen that as a result of use of satellite data the deviations from the synoptic analysis were somewhat decreased: the mean discrepancy was reduced from 4.72 to 4.07 dam, there were approximately 7% fewer points with considerable discrepancies (greater than 6 dam), and there was an increase in the number of points with small deviations. Table 2 gives spectral evaluations d^2. Here it can be seen that allowance for satellite data made it possible to bring the numerical analysis close to the synoptic analysis in all parts of the spectrum, except for the most short-wave part ($m \geqslant 10$). Still another characteristic which can be used is the kinetic energy of the thermal wind (Table 3), which in the variants AS and Syn was extremely close.

As an illustration, Fig. 1 shows a chart analyzed by a weatherman at the USSR Hydrometeorological Center for 0000 hours on 28 April 1977 and numerical analysis charts corresponding to the variants A, AS and the results of a comparison of these variants.

Allowance for satellite information led to substantial changes over ocean areas and brought the analysis close to the synoptic analysis. In the region of the Atlantic Ocean to the west of Great Britain a region of cold developed, although less deep and somewhat displaced in comparison with the weatherman's chart. Northeast of the shores of South America the heat ridge became clearer. Over the Pacific Ocean, in the region of the northwestern shores of North America, in variant AS in comparison with variant A the analysis came close to the weatherman's variant. The maximum difference between variants A and AS here attains 35 dam.

For evaluating the influence of satellite data on a forecast we computed forecasts for 48 hours in advance using the model in [1, 4]. Allowance for satellite information reduced d^2 from 16.4 to 14.7 dam^2. However, this conclusion must be checked on the basis of a large number of cases.

We note in conclusion that the cited results indicate the desirability of using spatial-temporal optimum interpolation in the four-dimensional analysis of aerological and satellite measurements.

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NUMERICAL MODEL OF ATMOSPHERIC DYNAMICS ON A SPHERICAL EARTH

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 11-23

[Article by Doctor of Physical and Mathematical Sciences V. V. Penenko and Candidate of Physical and Mathematical Sciences N. N. Obraztsov, USSR Hydrometeorological Scientific Research Center, submitted for publication 28 April 1978]

Abstract: The authors examine a numerical model of atmospheric dynamics in isobaric coordinates on a sphere. The discretization of the model is accomplished on the basis of the integral identity approximation. The article cites examples of use of the model for solving the problem of weather forecasting in an adiabatic approximation for a time up to five days.

[Text] This paper describes a numerical model for the modeling of the dynamics of atmospheric processes on a spherical earth in an isobaric coordinate system. The process of formulating finite-difference approximations is formulated on the basis of a determination of a generalized solution, discretization of the integral identity and the conditions of stationarity of the summator functional arising in this case [2, 8]. As a result, we obtain a family of energy-balanced finite-difference schemes whose structure is determined by the grid region, elementary operators for replacing the first derivatives of the space variables and the quadrature formulas for approximating the integrals in the identity. For constructing a scheme for integration in time we employ the splitting method and the weak approximation method.

1. Now we will examine a system of equations in hydrothermodynamics used for describing atmospheric processes on a spherical earth in an isobaric coordinate system [3]:

$$\frac{du}{dt} + \frac{\operatorname{ctg}\theta}{a} uv + lv + \frac{1}{a\sin\theta}\frac{\partial H}{\partial \varphi} = 0, \qquad (1.1a)$$

$$\frac{dv}{dt} - \frac{\operatorname{ctg}\theta}{a} u^2 - lu + \frac{1}{a}\frac{\partial H}{\partial \theta} = 0, \qquad (1.1b)$$

$$\frac{dT}{dt} - \frac{\gamma_a - \gamma}{gp} R\overline{T}\tau = \varepsilon, \qquad (1.1c)$$

$$T = -\frac{p}{R}\frac{\partial H}{\partial p}, \qquad (1.1d)$$

$$\operatorname{div}\vec{u} = 0, \qquad (1.1e)$$

where t is time, ψ is longitude, θ is the complement to latitude, p is pressure, $\vec{u} = (u, v, \tau)$ is the wind velocity vector, T, H are the deviations of temperature and geopotential from the standard values $\overline{T}(p)$ and $\overline{H}(p)$, γ, γ_a are the gradient of standard temperature and the adiabatic temperature gradient respectively, $l = 2\Omega\cos\theta$ is the Coriolis parameter, Ω is the angular velocity of the earth's rotation, a is the earth's radius, g is the acceleration of free falling, ε is a function of space coordinates and time describing the nonadiabatic heat influxes to a unit volume,

$$\frac{d\varphi}{dt} = \frac{\partial\varphi}{\partial t} + \frac{u}{a\sin\theta}\frac{\partial\varphi}{\partial\psi} + \frac{v}{a}\frac{\partial\varphi}{\partial\theta} + \tau\frac{\partial\varphi}{\partial p},$$

$$\operatorname{div}\varphi\vec{u} = \frac{1}{a\sin\theta}\left(\frac{\partial\varphi u}{\partial\psi} + \frac{\partial\varphi v\sin\theta}{\partial\theta}\right) + \frac{\partial\varphi\tau}{\partial p}.$$

In the derivation of equations (1.1) we used the assumptions of the free convection method, and also assumptions concerning quasistaticity of atmospheric processes.

A solution of equation (1.1) will be sought in the region

$$D_t = \{0 \leqslant t \leqslant \tilde{t}\} \times D, \quad D = D_s \times D_p,$$
$$D_s = \{0 \leqslant \psi \leqslant 2\pi,\ \theta^0 \leqslant \theta \leqslant \theta^1\},\ D_p = \{p^0 \leqslant p < p^1\}, \qquad (1.2)$$

where p^0 and p^1 is the pressure at the upper and lower boundaries of the atmosphere respectively, $\theta^0 \geqslant 0$ and $\theta^1 < \pi$ are given values determining the region of change in θ.

As the boundary conditions for system (1.1) we will use the following [3]:

$$\tau = 0 \quad \text{with} \quad p = p^0,$$

$$\tau = \frac{p}{R\overline{T}}\left(\frac{\partial H}{\partial t} + \frac{u}{a\sin\theta}\frac{\partial H}{\partial\psi} + \frac{v}{a}\frac{\partial H}{\partial\theta}\right) \quad \text{with} \quad p = p^1. \qquad (1.3)$$

The functions u, v, τ, H, T will be considered periodic relative to ψ with the period 2π.

In a case when the region D_s is part of a sphere, that is, when $\theta^0 \neq 0$, $\theta^1 \neq \pi$, as the additional boundary conditions we assume

$$v = 0 \quad \text{with} \quad \theta = \theta^0 \neq 0, \; \theta = \theta^1 \neq \pi. \tag{1.4}$$

In addition, we will assume that at the poles $\theta = 0$, $\theta = \pi$ the H and T functions were determined unambiguously and the horizontal components of the velocity vector $\vec{u}$ form a single-parameter rotation group continuously dependent on ψ:

$$\begin{cases} T(t, \psi, \theta, p) = T(t, p) \\ H(t, \psi, \theta, p) = H(t, p) \end{cases} \quad \text{with} \quad \theta = 0, \; \theta = \pi. \tag{1.5}$$

$$\begin{cases} u = U_\alpha \cos\psi - V_\alpha \sin\psi \cos\alpha \\ v = U_\alpha \sin\psi \cos\alpha + V_\alpha \cos\psi \end{cases} \quad \text{with} \quad \alpha = 0, \; \alpha = \pi,$$

where U_α and V_α ($\alpha = 0, \pi$) are dependent only on t and p.

We will transform the nonlinear terms in the system of equations (1.1) using the continuity equation (1.1e) to an antisymmetric form [8].

We will determine the function τ from equation (1.1c) and we will substitute the corresponding expression into the continuity equation (1.1e). Replacing the T function through the equation of quasistatics (1.1d), we finally arrive at the following system of equations:

$$\begin{gathered} \frac{\partial u}{\partial t} + G(\vec{u})\, u + \frac{\operatorname{ctg}\theta}{a} uv + lv + \frac{1}{a \sin\theta} \frac{\partial H}{\partial \psi} = 0, \\ \frac{\partial v}{\partial t} + G(\vec{u})\, v - \frac{\operatorname{ctg}\theta}{a} u^2 - lu + \frac{1}{a} \frac{\partial H}{\partial \theta} = 0, \\ -\frac{\partial}{\partial p} \alpha \frac{\partial}{\partial p} \frac{\partial H}{\partial t} - \frac{\partial}{\partial p} \alpha G(\vec{u}) \frac{\partial H}{\partial p} + \operatorname{Div} \vec{u} = \frac{\partial \alpha\tau}{\partial p}. \end{gathered} \tag{1.6}$$

In the system of equations (1.6) the following notations were used

$$\alpha = \alpha(p) = \frac{gp^2}{R^2 \bar{T} (\gamma_a - \gamma)}, \quad \operatorname{Div} \varphi \vec{u} = \operatorname{div} \varphi \vec{u} - \frac{\partial \varphi\tau}{\partial p},$$

$$G(\vec{u})\, \varphi = \frac{1}{2} (\vec{u} \cdot \nabla\varphi + \operatorname{Div} \varphi \vec{u}) \equiv \frac{1}{2} \left(\frac{u}{a \sin\theta} \frac{\partial \varphi}{\partial \psi} + \right. \tag{1.7}$$

$$\left. + \frac{v}{a} \frac{\partial \varphi}{\partial \theta} + \operatorname{Div} \varphi \vec{u} \right).$$

The boundary value conditions (1.3), in accordance with the transformations made and the assumption of smallness of the convective terms, assume the form

$$-\alpha \frac{\partial}{\partial p}\frac{\partial H}{\partial t} - \alpha G(\vec{u}) \frac{\partial H}{\partial p} = \alpha\tau \qquad \text{with} \quad p = p^0,$$

$$+\alpha \frac{\partial}{\partial p}\frac{\partial H}{\partial t} - \alpha G(\vec{u}) \frac{\partial H}{\partial p} = \alpha\tau + \beta \frac{\partial H}{\partial t} + \beta G(\vec{u}) H \quad \text{with} \quad p = p^1, \tag{1.8}$$

where $\beta = p/R\overline{T}$.

We will fix some elementary time interval

$$t \in [t_n, \quad t_{n+1}] \subset [0, \tilde{t}]$$

and we will examine the system of equations (1.6), (1.8) in this interval. The nonlinear operators $G(\vec{u})$ and ctg θ/a·u, on the assumption of an adequate smoothness of the functions u and v, will be approximated by linear operators using the formulas

$$G(\vec{u})\varphi \simeq G(\vec{u}^n)\varphi, \quad \frac{\operatorname{ctg}\theta}{a} u\varphi \simeq \frac{\operatorname{ctg}\theta}{a} u^n\varphi, \tag{1.9}$$

where $\vec{u}^n = \vec{u}|_{t=t_n}$.

We will assume that the linearized system of equations (1.6), (1.8) allows a sufficiently smooth solution $\{u, v, H\}$ from function space Φ in which the scalar product

$$(\varphi, \tilde{\varphi}) = \int\limits_{t_n}^{t_{n+1}} \int\limits_0^{2\pi} \int\limits_0^{\pi} \int\limits_{p^0}^{p^1} \varphi\tilde{\varphi} a^2 \sin\theta \, dp \, d\theta \, d\psi \, dt. \tag{1.10}$$

was determined.

We will multiply the system (1.6), scalarly linearized with the expressions (1.9) taken into account, by $\tilde{u}$, $\tilde{v}$, $\tilde{H}$ respectively and we will sum the result. Integrating by parts the expressions containing the differential operators and taking the boundary value conditions into account, we obtain

$$J(\vec{\Phi}, \vec{\tilde{\Phi}}) = (B(\vec{\Phi}, \vec{\tilde{\Phi}}), 1), \tag{1.11}$$

where

$$B(\vec{\Phi}, \vec{\tilde{\Phi}}) = A(u, \tilde{u}) + A(v, \tilde{v}) + \alpha A\left(\frac{\partial H}{\partial p}, \frac{\partial \tilde{H}}{\partial p}\right) +$$

$$+ \left(\frac{u^n \operatorname{ctg}\theta}{a} + l\right)(\tilde{u}v - \tilde{v}u) + \tilde{H} \operatorname{Div} \vec{u} - H \operatorname{Div} \vec{\tilde{u}} -$$

$$- \frac{\partial \alpha\tau}{\partial p}\tilde{H} + \frac{1}{p^1 - p^0}\left[\frac{\beta}{2} A(H, \tilde{H})|_{p=p^1} + \alpha\tau\tilde{H}|_{p^0}^{p^1}\right] +$$

$$+ \frac{1}{t_{n+1} - t_n}\left[u\tilde{u} + v\tilde{v} + \alpha \frac{\partial H}{\partial p}\frac{\partial \tilde{H}}{\partial p} + \frac{\beta H\tilde{H}}{p^1 - p^0}\Big|_{p=p^1}\right]\Bigg|_{t_n}^{t_{n+1}}.$$

$$A(\varphi, \tilde{\varphi}) = \frac{1}{2}\left(\tilde{\varphi}\frac{\partial\varphi}{\partial t} - \varphi\frac{\partial\tilde{\varphi}}{\partial t} + \tilde{\varphi}\vec{u}^n \cdot \nabla\varphi - \varphi\vec{u}^n \cdot \nabla\tilde{\varphi}\right), \quad \vec{\Phi} = (u, v, H).$$

We will use expression (1.11) as a determination of the generalized solution of the system of equations (1.6), (1.8) linearized in the interval $[t_n, t_{n+1}]$ and we will assume to be a solution of the problem the functions u, v, H, such that

$$J(\vec{\Phi}, \vec{\tilde{\Phi}}) = 0 \tag{1.12}$$

for any adequately smooth functions $\tilde{u}$, $\tilde{v}$, $\tilde{H}$. The integral identity (1.12) with $\tilde{u} = u$, $\tilde{v} = v$, $\tilde{H} = H$, without additional transformations is transformed into the expression for the energy balance for the system of equations (1.7), (1.8):

$$\int_0^{2\pi}\int_{\theta^0}^{\theta^1}\left[\int_{p^0}^{p^1}\left(u^2 + v^2 + \alpha\left(\frac{\partial H}{\partial p}\right)^2\right)dp + \beta H^2|_{p=p^1}\right]\Bigg|_{t_n}^{t_{n+1}} a^2\sin\theta\, d\theta\, d\psi = \tag{1.13}$$

$$= 2\int_{t_n}^{t_{n+1}}\int_0^{2\pi}\int_{\theta^0}^{\theta^1}\left[\int_{p^0}^{p^1}\frac{\partial æ}{\partial p}H\,dp - æ H\Big|_{p^0}^{p^1}\right]a^2\sin\theta\, d\theta\, d\psi\, dt.$$

With an equality of the Ɛ function to zero the expression (1.13) is the energy conservation law for the system of equations (1.7), (1.8).

Thus, in determinations of a generalized solution by means of the functional identity (1.12) we have taken into account the relationship of the energy balance characteristic of this system of equations.

2. The system of equations (1.6), (1.8), linearized in the interval $[t_n, t_{n+1}]$, will be solved by finite difference methods. In the region $D_s \times D_p$ we will determine the grid region as the direct product of one-dimensional grids in the direction of the coordinates ψ, θ, p:

$$D^h = D_s^h \times \omega_p, \quad D_s^h = \omega_\psi \times \omega_\theta, \tag{2.1}$$

where

$$\omega_\psi = \left\{\psi_i \in [0, 2\pi] \mid \psi_i = i\,\delta\psi,\ i = \overline{0, 2N-1},\ \delta\psi = \frac{\pi}{N}\right\}$$

$$\omega_\theta = \left\{\theta_j \in [\theta^0, \theta^1] \mid \theta_j = \theta^0 + j\,\delta\theta,\ j = \overline{0, M},\ \delta\theta = \frac{\theta^1 - \theta^0}{M}\right\}$$

$$\omega_p = \left\{p_k \in [p^0, p^1] \mid p_k = p^0 + k\,\delta p,\ k = \overline{0, K},\ \delta p = \frac{p^1 - p^0}{K}\right\}.$$

We introduce into consideration the space of grid functions Φ^h, determined in the grid D^h:

$$\Phi^h = \{\vec{\varphi} = \{\varphi_{ijk}\} \mid \varphi_{ijk} = \varphi(t, \psi_i, \theta_j, p_k), \; i = \overline{0, 2N-1}, \; j = \overline{0, M}, \quad k = \overline{0, K}\}. \tag{2.2}$$

We will consider the functions $\vec{\varphi} \in \Phi^h$ to be periodic with respect to the index i with the period 2N. In addition, the functions $\vec{u}$, $\vec{v}$, $\vec{H}$ at the poles $\theta = 0$, $\theta = \pi$ satisfy the discrete analogues of the relationships (1.5). In the space of grid functions Φ^h we will stipulate the scalar product by the following formula:

$$(\vec{\varphi}, \vec{\tilde{\varphi}}) = \sum_{i=0}^{2N-1} \sum_{j=0}^{M} \sum_{k=0}^{K} \varphi_{ijk} \tilde{\varphi}_{ijk} a^2 s_j \delta\psi\delta\theta \Delta p_k, \tag{2.3}$$

where

$$s_j = \begin{cases} \sin\theta_j & (j = \overline{1, M-1}) \\ \dfrac{1 - \cos\delta\theta}{2\,\delta\theta} & (j = 0, M;\; \theta^0 = 0,\; \theta^1 = \pi) \\ \dfrac{\sin\theta_j}{2} & (j = 0, M;\; \theta^0 \neq 0,\; \theta^1 \neq \pi) \end{cases} \quad \Delta p_k = \begin{cases} \delta p \; (k = \overline{1, K-1}) \\ \dfrac{\delta p}{2} \; (k = 0, K). \end{cases}$$

The finite-difference approximations of the system of equations (1.6), (1.8), linearized in the interval $t \in [t_n, t_{n+1}]$ will be constructed on the basis of the functional identity (1.12) [7, 8]. In order to approximate the integrals of space variables in expression (1.12) we use quadrature formulas of the trapezium formula type. The integrals of the variables ψ, θ in the neighborhood of the poles will be approximated in the following way:

$$\int_0^{2\pi} \int_0^{\delta\theta/2} \varphi \sin\theta \, d\theta \, d\psi \simeq \sum_{i=0}^{2N-1} \varphi_{i0} s_0 \delta\psi. \tag{2.4}$$

We will use a similar formula for the pole $\theta = \pi$. With the replacement of the integrals by quadrature formulas we take into account relationships (1.5) and we will assume that the functions $\tilde{u}$, $\tilde{v}$, $\tilde{H}$ also satisfy these relationships. As a result we obtain

$$J(\vec{\Phi}, \vec{\tilde{\Phi}}) \approx \int_{t_n}^{t_{n+1}} (\vec{B}, 1) \, dt, \tag{2.5}$$

where $$\vec{B} = \{B_{ijk},\ i = \overline{0,\ 2N-1},\ j = \overline{0,\ M},\ k = \overline{0,\ K}\},$$

$$\begin{cases} B_{ijk} = B\left(\vec{\Phi}(t,\ \psi_i,\ \theta_j,\ p_k),\ \vec{\tilde{\Phi}}(t,\ \psi_i,\ \theta_j,\ p_k)\right),\ (j = \overline{1,\ M-1}) \\ B_{ijk} = \Big[\tilde{A}(u,\ \tilde{u}) + \tilde{A}(v,\ \tilde{v}) + \alpha\tilde{A}\left(\frac{\partial H}{\partial p},\ \frac{\partial \tilde{H}}{\partial p}\right) + l(\tilde{u}v - \tilde{v}u) - \\ -\frac{\partial\alpha\varepsilon}{\partial p}\tilde{H} + \frac{1}{p^1 - p^0}\left(\frac{\beta}{2}\tilde{A}(H,\ \tilde{H})\big|_{p=p^1} + \alpha\varepsilon\tilde{H}\big|_{p^0}^{p^1}\right) + \\ + \frac{1}{t_{n+1} - t_n}\left(u\tilde{u} + v\tilde{v} + \alpha\frac{\partial H}{\partial p}\frac{\partial \tilde{H}}{\partial p} + \frac{\beta H\tilde{H}}{p^1 - p^0}\bigg|_{p=p^1}\right)\bigg|_{t_n}^{t_{n+1}}\Big]_{ijk} + \\ + j_1\Big[\tilde{A}^h(u,\ \tilde{u}) + \tilde{A}^h(v,\ \tilde{v}) + \alpha\tilde{A}^h\left(\frac{\partial H}{\partial p},\ \frac{\partial \tilde{H}}{\partial p}\right) + \\ + \frac{\beta}{2(p^1 - p^0)}\tilde{A}^h(H,\ \tilde{H})\big|_{p=p^1} + \frac{1}{\alpha\,\delta\theta}\,(H_{ik}\tilde{v}_{ij+j_1k} - \\ - \tilde{H}_{jk}v_{ij+j_1k})\Big],\ (j = 0,\ M) \\ (i = \overline{0,\ 2N-1},\ \ k = \overline{0,\ K}) \end{cases}$$

$$\tilde{A}(\varphi,\ \tilde{\varphi}) = \frac{1}{2}\left(\tilde{\varphi}\frac{\partial\varphi}{\partial t} - \varphi\frac{\partial\tilde{\varphi}}{\partial t}\right),\quad j_1 = \operatorname{sign}(1 - j),$$

$$\tilde{A}^h(\varphi,\ \tilde{\varphi}) = \frac{v_{ijk}^h}{2a\,\delta\theta}\left(\tilde{\varphi}_{ijk}\varphi_{ij+j_1k} - \varphi_{ijk}\tilde{\varphi}_{ij+j_1k}\right).$$

In a case when the D_S region is part of a sphere, the quadrature formulas are written uniformly for the entire region, taking into account the boundary condition (1.4).

Assume now that we have the stipulated difference operators Λ_ψ, $\bar{\Lambda}_\psi$, Λ_θ, $\bar{\Lambda}_\theta$, Λ_p, approximating the differential operators

$$\frac{\partial}{\partial\psi},\ \frac{\partial}{\partial\theta},\ \frac{\partial}{\partial p}$$

at the points of intersection in the grid region D^h (2.1). The smoothness of the functions u, v, H, $\tilde{u}$, $\tilde{v}$, $\tilde{H}$ will be considered adequate for satisfying the relationships

$$\left[\frac{\partial\varphi}{\partial\psi}\right]_{ijk} = [\Lambda_\psi\vec{\varphi}]_{ijk} + \varepsilon_\psi,\quad (j = \overline{1,\ M-1}),$$

$$\left[\frac{\partial\varphi}{\partial\psi}\right]_{ijk} = [\bar{\Lambda}_\psi\vec{\varphi}]_{ijk} + \bar{\varepsilon}_\psi,\quad (j = \overline{1,\ M-1}),$$

$$\left[\frac{\partial\varphi}{\partial\theta}\right]_{ijk} = [\Lambda_\theta\vec{\varphi}]_{ijk} + \varepsilon_\theta,\quad (j = \overline{1,\ M-1}),$$

$$\left[\frac{\partial \varphi}{\partial \theta}\right]_{ijk} = [\bar{\Lambda}_\theta \vec{\varphi}]_{ijk} + \varepsilon_\theta, \quad (j = \overline{1, M-1}),$$

$$\left[\frac{\partial \varphi}{\partial p}\right]_{ijk} = [\Lambda_p \vec{\varphi}]_{ijk} + \varepsilon_p, \quad (j = \overline{0, M}), \tag{2.6}$$

$$(i = \overline{0, 2N-1}, \quad k = \overline{0, K}),$$

where ε_x are functions dependent on i, j, k and determining the error in approximating the corresponding differential operators.

We will supplement the operators Λ_θ, $\bar{\Lambda}_\theta$ in the neighborhood of the poles in accordance with the form of the functional (2.5). For example, with j = 0 we will assume that

$$[\Lambda_\theta \vec{\varphi}]_{i0k} = \frac{\varphi_{i1k}}{\delta\theta}, \quad [\bar{\Lambda}_\theta \vec{\varphi}]_{i0k} = \frac{\varphi_{i1k}}{\delta\theta} \tag{2.7}$$

$$(i = \overline{0, 2N-1}, \quad k = \overline{0, K}).$$

Using the difference analogues of the differential operators from (2.6), (2.7) and taking into account the determination of the scalar product (2.7) in the space of grid functions Φ^h, we reduce expression (2.5) to the following form:

$$\begin{aligned} J(\vec{\Phi}, \vec{\tilde{\Phi}}) \simeq \int_{t_n}^{t_{n+1}} \Bigg\{ \Bigg(& \Big(\vec{\tilde{u}}, \frac{1}{2} \frac{\partial \vec{u}}{\partial t} + \frac{1}{2a}(\Lambda_1 + \Lambda_2)\vec{u} + (L + U^n C)\vec{v} - \\ & - S^{-1}\bar{\Lambda}_\psi^\tau \vec{H}\Big) + \Big(\vec{\tilde{v}}, \frac{1}{2}\frac{\partial \vec{v}}{\partial t} + \frac{1}{2a}(\Lambda_1 + \Lambda_2)\vec{v} - (L + U^n C)\vec{u} - \bar{\Lambda}_\theta^\tau \vec{H}\Big) + \\ & + \Big(\vec{\tilde{H}}, \frac{1}{2}\frac{\partial}{\partial t}\Lambda_3 \vec{H} + \frac{1}{2a}(\tilde{\Lambda}_1 + \tilde{\Lambda}_2)\vec{H} + S^{-1}\bar{\Lambda}_\psi \vec{u} + S^{-1}\bar{\Lambda}_\theta S\vec{v}\Big) - \\ & - \frac{1}{2}\Big[\Big(\vec{u}, \frac{\partial \vec{\tilde{u}}}{\partial t}\Big) + \Big(\vec{v}, \frac{\partial \vec{\tilde{v}}}{\partial t}\Big) + \Big(\vec{H}, \frac{\partial}{\partial t}\Lambda_3 \vec{\tilde{H}}\Big)\Big] + \\ & + \frac{\theta_K}{\Delta p_K}\Big[\Big(\vec{\tilde{H}}_K, \frac{\partial \vec{H}_K}{\partial t} + \frac{1}{a}(\Lambda_1 + \Lambda_2)\vec{H}_K\Big) - \Big(\vec{H}_K, \frac{\partial \vec{\tilde{H}}_K}{\partial t}\Big)\Big] - \\ & - (\vec{\tilde{H}}, \Lambda_p \bar{\alpha} \vec{\varepsilon}) + \frac{\gamma_K}{\Delta p_K}(\vec{\tilde{H}}_k, \vec{\varepsilon}_k)\Big|_0^K \Bigg\} dt + \frac{1}{2}\Big[(\vec{\tilde{u}}, \vec{u}) + (\vec{\tilde{v}}, \vec{v}) + \\ & + (\vec{\tilde{H}}, \Lambda_3 \vec{H}) + \frac{\vartheta_K}{\Delta p_K}(\vec{\tilde{H}}_K, \vec{H}_K)\Big]\Bigg|_{t_n}^{t_{n+1}}. \end{aligned} \tag{2.8}$$

In expression (2.8) we used the following notations:

$$\begin{aligned}
\Lambda_1 &= S^{-1}(U^n\Lambda_\psi - \Lambda_\psi^T U^n),\\
\overline{\Lambda}_1 &= \overline{P}^{-1}\Lambda_p^T \overline{P}\overline{\alpha}\Lambda_1\Lambda_p,\\
\Lambda_2 &= S^{-1}(SV^n\Lambda_\theta - \Lambda_\theta^T V^n S),\\
\overline{\Lambda}_2 &= \overline{P}^{-1}\Lambda_p^T \overline{P}\overline{\alpha}\Lambda_2\Lambda_p,\\
\Lambda_3 &= \overline{P}^{-1}\Lambda_p^T \overline{P}\overline{\alpha}\Lambda_p,
\end{aligned}\tag{2.9}$$

U^n, V^n, S, $\overline{\alpha}$, C, L, $\overline{P}$ are block-diagonal matrices, on the diagonals of which are situated the values u^n_{ijk}, v^n_{ijk}, s_j, α_k, ctg θ_j, l_j, Δp_k respectively in the order determined by the structure of the vectors from the space Φ^h (2.2),

$$\ddot{\varphi}_r = \left\{\varphi_{ijk} \,\middle|\, \varphi_{ijk} = \begin{cases} 0 & k=\overline{0, K},\ k\neq r\\ \varphi_{ijr}, & k=r\end{cases}\ \middle|\ i=\overline{0, 2N-1},\ j=\overline{0, M}\right\},$$

the T superscript denotes the transpositioning operation.

Now we will proceed to formulation of an approximation for expression (2.8) with respect to the variable t. For this purpose we will examine an identity correct for the arbitrary operators A_1, A_2:

$$\int_a^b\left(\tilde{\varphi}\frac{\partial\varphi}{\partial t} - \varphi\frac{\partial\tilde{\varphi}}{\partial t} + \tilde{\varphi}A_1\varphi + \tilde{\varphi}A_2\varphi\right)dt + \varphi\tilde{\varphi}\Big|_a^b = \tag{2.10}$$

$$= \int_a^{(a+b)/2}\left(\tilde{\varphi}\frac{\partial\varphi}{\partial t} - \varphi\frac{\partial\tilde{\varphi}}{\partial t}\right)dt + \int_a^b \tilde{\varphi}A_1\varphi\,dt + \varphi\tilde{\varphi}\Big|_a^{\frac{a+b}{2}} +$$

$$+ \int_{(a+b)/2}^b\left(\tilde{\varphi}\frac{\partial\varphi}{\partial t} - \varphi\frac{\partial\tilde{\varphi}}{\partial t}\right)dt + \int_a^b \tilde{\varphi}A_2\varphi\,dt + \varphi\tilde{\varphi}\Big|_{\frac{a+b}{2}}^b .$$

We will transform the functional (2.8), with the identity (2.10) taken into account. Using for an approximation of the terms of the same kind quadrature formulas of the trapezium formula type, we obtain the expression:

$$J(\vec{\Phi}, \vec{\tilde{\Phi}}) \approx J^h(\vec{\Phi}, \vec{\tilde{\Phi}}) = (0, u, u, E, \Lambda_1) + (0, v, v, E, \Lambda_1) +$$

$$+ (1/4, u, v, E, 2U^nC) + (1/4, v, u, E, -2U^nC) +$$

$$
\begin{aligned}
&+(0,\ H,\ H,\ \Lambda_3,\ \overline{\Lambda}_1)+\left(0,\ H_K,\ H_K,\ \frac{\beta_K}{\Delta p_K}E,\ \frac{\beta_K}{\Delta p_K}\Lambda_1\right)+\\
&+(1/2,\ u,\ u,\ E,\ \Lambda_2)+(1/2,\ v,\ v,\ E\ \Lambda_2)+(1/4,\ H,\ H,\ \Lambda_3,\ \overline{\Lambda}_2)+\\
&+\left(1/4,\ H_K,\ H_K,\ \frac{\beta_K}{\Delta p_K}E,\ \frac{\beta_K}{\Delta p_K}\Lambda_2\right)+[3/4,\ u,\ v,\ H,\ E,\ aL,\ -S^{-1}\overline{\Lambda}_\psi^{\tau}]+\\
&+[3/4,\ v,\ u,\ H,\ E,\ -aL,\ -\overline{\Lambda}_\theta^{\tau}]+[1/2,\ H,\ u,\ v,\ \Lambda_3,\ S^{-1}\overline{\Lambda}_\psi,\\
&S^{-1}\overline{\Lambda}_\theta S]+\left(1/2,\ H_K,\ H_K,\ \frac{\beta_K}{\Delta p_K}E,\ 0\right)+(3/4,\ H,\ \varepsilon,\ \Lambda_3,\ 2a\Lambda_p\overline{\alpha})-\\
&-\left(3/4,\ H_0,\ \varepsilon_0,\ \frac{1}{\Delta p_0}E,\ \frac{2a\alpha_0}{\Delta p_0}E\right)+\left(3/4,\ H_K,\ \varepsilon_K,\ \frac{1}{\Delta p_K}E,\right.\\
&\left.\frac{2a\alpha_K}{\Delta p_K}E\right),
\end{aligned}
\tag{2.11}
$$

where

$$
\begin{aligned}
(m-n,\ \varphi_1,\ \varphi_2,\ A_1,\ A_2)\equiv(\vec{\tilde{\varphi}}_1^{m+1/8},\ A_1(\vec{\varphi}_1^{m+1/4}-\vec{\varphi}_1^{m})&+\\
+\frac{\delta t}{2a}A_2\frac{\vec{\varphi}_2^{m+1/4}+\vec{\varphi}_2^{m}}{2}\Big)&,
\end{aligned}
$$

$$
\begin{aligned}
[m-n,\ \varphi_1,\ \varphi_2,\ \varphi_3,\ A_1,\ A_2,\ A_3]\equiv(\vec{\tilde{\varphi}}_1^{m+1/8},\ A_1(\vec{\varphi}_1^{m+1/4}-\vec{\varphi}_1^{m})&+\\
+\frac{\delta t}{a}\left(A_2\frac{\vec{\varphi}_2^{m+1/4}+\vec{\varphi}_2^{m}}{2}+A_3\frac{\vec{\varphi}_3^{m+1/4}+\vec{\varphi}_3^{m}}{2}\right)\Big)&,
\end{aligned}
$$

E , 0 are the identity and zero operators respectively.

Thus, the functional identity (1.12) is approximated by the summator identity

$$J^h(\vec{\Phi},\ \vec{\tilde{\Phi}})=0. \tag{2.12}$$

We use the identity (2.12) as a determination of the generalized solution for the difference analogue of the system of equations (1.7), (1.8). The corresponding system of finite-difference equations is determined by the expressions

$$\frac{\partial J^h}{\partial\vec{\tilde{u}}}=0,\ \frac{\partial J^h}{\partial\vec{\tilde{v}}}=0,\ \frac{\partial J^h}{\partial\vec{\tilde{H}}}=0. \tag{2.13}$$

Equations (2.13) represent the conditions of nondependence of variations of the summator functional $J^h(\vec{\Phi}, \vec{\tilde{\Phi}})$ on the variations of the grid functions $\vec{\tilde{u}}, \vec{\tilde{v}}, \vec{\tilde{H}}$. The system of equations (2.13) approximates the initial problem (1.6), (1.8) in the time interval $[t_n, t_{n+1}]$ with the error

$$|\min(\varepsilon_\psi, \bar{\varepsilon}_\psi), \min(\varepsilon_\theta, \bar{\varepsilon}_\theta), \varepsilon_p, \delta t|$$

with respect to the variables ψ, θ, p, t respectively. With a choice of the trial functions $\vec{\tilde{u}} = u$, $\vec{\tilde{v}} = v$, $\vec{\tilde{H}} = \vec{H}$ the summator identity (2.12) is transformed into the energy balance relationship for the system of equations (2.13)

$$J^h(\vec{\Phi}, \vec{\Phi}) = \frac{1}{2}\Big[(\vec{u}, \vec{u}) + (\vec{v}, \vec{v}) + (\vec{H}, \Lambda_3 \vec{H}) + \frac{\beta_K}{\Delta p_K}(\vec{H}_K, \vec{H}_K)\Big]\Big|_{t_n}^{t_{n+1}} - \frac{\delta t}{2}\Big[(\vec{H}^{n+1} + \vec{H}^{n+1/4}, \Lambda_p \vec{\alpha\varepsilon}) + \Big(\vec{H}_k^{n+1} + \vec{H}_k^{n+3/4}, \frac{\alpha_k}{\Delta p_k}\vec{\varepsilon}_k\Big)\Big|_0^K\Big] = 0. \qquad (2.14)$$

Expression (2.14) when $\vec{\varepsilon} = 0$ is the energy conservation law for the system of equations (2.13):

$$\Big[(\vec{u}, \vec{u}) + (\vec{v}, \vec{v}) + (\vec{H}, \Lambda_3 \vec{H}) + \frac{\beta_K}{\Delta p_K}(\vec{H}_K, \vec{H}_K)\Big]\Big|_{t_n}^{t_{n+1}} = 0. \qquad (2.15)$$

The system of equations (2.13) in expanded form is written in the following form:

$$\left|\begin{array}{l}
\left(E + \frac{\delta t}{4a}\Lambda_1\right)\vec{u}^{n+1/4} = \left(E - \frac{\delta t}{4a}\Lambda_1\right)\vec{u}^n \\
\left(E + \frac{\delta t}{4a}\Lambda_1\right)\vec{v}^{n+1/4} = \left(E - \frac{\delta t}{4a}\Lambda_1\right)\vec{v}^n \\
\begin{vmatrix} E & \frac{\delta t}{2a}U^n C \\ -\frac{\delta t}{2a}U^n C & E \end{vmatrix} \begin{vmatrix} \vec{u}^{n+1/2} \\ \vec{v}^{n+1/2} \end{vmatrix} = \begin{vmatrix} E & -\frac{\delta t}{2a}U^n C \\ \frac{\delta t}{2a}U^n C & E \end{vmatrix} \begin{vmatrix} \vec{u}^{n+1/4} \\ \vec{v}^{n+1/4} \end{vmatrix} \\
p^{-1}\Lambda_p^* \bar{p}\alpha \left(E + \frac{\delta t}{4a}\Lambda_1\right)\Lambda_p \vec{H}^{n+1/4} + \frac{\beta_K}{\Delta p_K}\left(E + \frac{\delta t}{4a}\Lambda_1\right)\vec{H}_K^{n+1/4} =
\end{array}\right. \qquad (2.16)$$

$$\left|\begin{aligned}
&= \overline{P}^{-1}\Lambda_p^{*}\overline{P}\overline{a}\left(E-\frac{\delta t}{4a}\Lambda_1\right)\Lambda_p\vec{H}^{n}+\frac{\beta_K}{\Delta p_K}\left(E-\frac{\delta t}{4a}\Lambda_1\right)\vec{H}_K^{n}\\
&\left(E+\frac{\delta t}{4a}\Lambda_2\right)\vec{u}^{n+3/4}=\left(E-\frac{\delta t}{4a}\Lambda_2\right)\vec{u}^{n+1/2}\\
&\left(E+\frac{\delta t}{4a}\Lambda_2\right)\vec{v}^{n+3/4}=\left(E-\frac{\delta t}{4a}\Lambda_2\right)\vec{v}^{n+1/2}\\
&\overline{P}^{-1}\Lambda_p^{*}\overline{P}\overline{a}\left(E+\frac{\delta t}{4a}\Lambda_2\right)\Lambda_p\vec{H}^{n+1/2}+\\
&+\frac{\beta_K}{\Delta p_K}\left(E+\frac{\delta t}{4a}\Lambda_2\right)\vec{H}_K^{n+1/2}=\overline{P}^{-1}\Lambda_p^{*}\overline{P}\overline{a}\left(E-\frac{\delta t}{4a}\Lambda_2\right)\times\\
&\times\Lambda_p\vec{H}^{n+1/4}+\frac{\beta_K}{\Delta p_K}\left(E-\frac{\delta t}{4a}\Lambda_2\right)\vec{H}_K^{n+1/4}.
\end{aligned}\right. \tag{2.16}$$

$$\left|\begin{aligned}
&\vec{u}^{n+1}-\vec{u}^{n+3/4}+\delta tL\,\frac{\vec{v}^{n+1}+\vec{v}^{n+3/4}}{2}-\\
&-\frac{\delta t}{a}S^{-1}\overline{\Lambda}_{\varphi}^{*}\,\frac{\vec{H}^{n+3/4}+\vec{H}^{n+1/2}}{2}=0\\
&\vec{v}^{n+1}-\vec{v}^{n+3/4}-\delta tL\,\frac{\vec{u}^{n+1}+\vec{u}^{n+3/4}}{2}-\\
&-\frac{\delta t}{a}\overline{\Lambda}_{\theta}^{*}\,\frac{\vec{H}^{n+3/4}+\vec{H}^{n+1/2}}{2}=0\\
&\Lambda_3(\vec{H}^{n+3/4}-\vec{H}^{n+1/2})+\frac{\delta t}{a}S^{-1}\left(\overline{\Lambda}_{\varphi}\,\frac{\vec{u}^{n+1}+\vec{u}^{n+3/4}}{2}+\right.\\
&\left.+\overline{\Lambda}_{\theta}S\,\frac{\vec{v}^{n+1}+\vec{v}^{n+3/4}}{2}\right)+\frac{\beta_K}{\Delta p_K}(\vec{H}_K^{n+3/4}-\vec{H}_K^{n+1/2})=0.
\end{aligned}\right. \tag{2.17}$$

$$\left|\begin{array}{l} \Lambda_2(\vec{H}^{n+1} - \vec{H}^{n+3/4}) + \frac{\theta_K}{\Delta p_K}(\vec{H}_K^{n+1} - \vec{H}_K^{n+3/4}) = \\ = \delta t \Lambda_p \overline{\alpha} \vec{z}^{n+7/8} + \frac{\delta t a_0}{\Delta p_0} \vec{z}_0^{n+7/8} - \frac{\delta t \alpha_K}{\Delta p_K} \vec{z}_K^{n+7/8}. \end{array}\right. \quad (2.18)$$

Now we will formulate the properties of the finite-difference approximation (2.16)-(2.18).

1) Difference operators, approximating differential operators in spatial variables, were introduced formally, that is, scheme (2.16)-(2.18) can be regarded as a class of schemes of different order of approximation in spatial variables.

2) Scheme (2.16)-(2.17) has a law of energy conservation in the form (2.15) for any approximations in spatial variables under the condition that expressions of the same type are approximated in a uniform way, that is, this scheme is absolutely stable in space metrics Φ^h (2.2).

3) Scheme (2.16)-(2.18) formally approximates problem (1.6), (1.18) with the first order of magnitude for the variable t (which corresponds to the order of approximation of the nonlinear operators of the initial problem by linear operators).

In order to formulate a second-order scheme in time, in (1.9) it is necessary to use a second-order approximation for the nonlinear terms and proceed to the corresponding quadrature formula in time. In particular, this is achieved by using in (1.9) an extrapolation formula in the form

$$\varphi^{n+1/2} \simeq \frac{4}{3}\varphi^n - \frac{1}{3}\varphi^{n-1}$$

and a two-cycle splitting scheme [4].

4) Scheme (2.16)-(2.18) is invariant to the choice of a family of grids. This means that the form of writing and the properties of the scheme do not change if in place of the grid region $D^h \subset D$ in the form (2.1) we use any other grid region.

3. Choice of the operators Λ, $\bar{\Lambda}_\psi$, Λ_θ, $\bar{\Lambda}_\theta$, Λ_p from (2.6), approximating the differential operators $\frac{\partial}{\partial\varphi}, \frac{\partial}{\partial\theta}, \frac{\partial}{\partial p}$ respectively, to an adequate degree is arbitrary. We will determine them in such a way as to ensure a second order of approximation of the differential operators

$$\frac{\partial^2}{\partial\varphi^2}, \frac{\partial}{\partial\theta}\sin\theta\frac{\partial}{\partial\theta}. \quad \text{by the operators} \quad \bar{\Lambda}_\varphi\bar{\Lambda}_\varphi, \bar{\Lambda}_\theta S \Lambda_\theta$$

and also a simple and effective numerical realization of the systems of equations (2.16)-(2.18):

$$\left\{\begin{array}{l}
[\Lambda_{\psi}\vec{\varphi}]_{ijk}=(\varphi_{i+1,\,jk}-\varphi_{i-1,\,jk})/2\,\delta\psi\\
[\overline{\Lambda}_{\psi}\vec{\varphi}]_{ijk}=(\varphi_{i+1,\,jk}-\varphi_{ijk})/\delta\psi\\
[\Lambda_{\theta}\vec{\varphi}]_{ijk}=(\varphi_{ij+1,\,k}-\varphi_{ij-1,\,k})/2\,\delta\theta\\
[\overline{\Lambda}_{\theta}\vec{\varphi}]_{ijk}=(\varphi_{ij+1,\,k}-\varphi_{ijk})/\delta\theta\\
(i=\overline{0,\,2N-1},\; j=\overline{1,\,M-1},\; k=\overline{0,\,K})
\end{array}\right. \qquad (3.1)$$

$$\left\{\begin{array}{l}
[\Lambda_{p}\vec{\varphi}]_{ijk}=(\varphi_{ij,\,k+1}-\varphi_{ijk})/\delta p\;\;(k=\overline{0,\,K-1})\\
[\Lambda_{p}\vec{\varphi}]_{ijK}=(\varphi_{ijK}-\varphi_{ij,\,K-1})/\delta p.\\
(i=\overline{0,\,2N-1},\;\; j=\overline{0,\,M})
\end{array}\right.$$

At the points j = 0, M the operators $\Lambda_{\theta}, \overline{\Lambda}_{\theta}$ are determined in accordance with (2.7).

The systems of equations (2.16), (2.17), with determination of the operators $\Lambda_{\psi}, \overline{\Lambda}_{\psi}, \Lambda_{\theta}, \overline{\Lambda}_{\theta}, \Lambda_{p}$ by formulas (3.1), are solved using direct algorithms based on fitting methods, the fast Fourier transform and the "edging" method [1, 5, 6, 10, 11].

For practical realization of this method a complex of programs was developed which is based on the principles of module programming. The basis for the complex is an "archives" of modular procedures, each of which realizes a part of one of the computation algorithms. The program for practical solution of the system of equations (2.16)-(2.18) in such an approach is a set of procedures from the "archives" of the complex, related to one another at the level of the input and output information, taking into account the structure of the considered problem.

4. In conclusion we will cite the results of numerical experiments using the model described above. In accordance with the meteorological information at our disposal, as the region of solution D (1.2) we select the northern hemisphere:

$$D=\{0<\psi<2\pi,\;\; 0\leqslant\theta\leqslant\pi/2,\;\; 100\text{ мб}\leqslant p\leqslant 1000\text{ мб}\}. \qquad (4.1)$$

The grid region $D^h \subset D$ (2.1) is determined in the following way:

$$D^h=\{\psi_i\in[0,\,2\pi]\,|\,\psi_i=i\,\delta\psi,\;\; i=\overline{0,35},\;\; \delta\psi=\pi/18,$$
$$\theta_j\in[0,\,\pi/2]\,|\,\theta_j=j\,\delta\theta,\;\; j=\overline{0,18},\;\; \delta\theta=\pi/36,\;\;\; p_k\in[100,\,1000]\,|\,k=\overline{1,7}\}. \qquad (4.2)$$

The intervals for the p variable are nonuniform and are determined by the distances between the isobaric surfaces in the standard atmosphere: (100, 200, 300, 500, 700, 850, 1000 mb).

The forecasting problem was solved for a time up to 5 days. In the computations we employed an adiabatic variant of the model. As the input information for the forming of initial data we used information from the USSR Hydrometeorological Center on the geopotential fields for December 1964. The initial wind fields were computed using data on geopotential fields using the model described in [9].

Table 1 gives the values of the mean relative error (numerator) and correlation coefficient (denominator) of the predicted and actual variabilities of the geopotential field. We took into account deviations exceeding 12 dam for the levels 100, 200, 300 mb, 8 dam for the level 500 mb, 4 dam for the levels 700, 850, 1000 mb. The estimates cited in this table were averaged using a series of 32 forecasts.

This numerical experiment pursues methodological purposes. In essence, in the course of this experiment we tested a complex consisting of a model of analysis and assimilation of the initial fields of meteorological elements, described in [9], and the model of atmospheric dynamics set forth in this article. The geopotential fields were stipulated at the points of intersection in a regular grid region and on the basis of the variational principle only the wind fields were reconstructed. Since the adiabatic variant of the model was used and no additional information was used other than the geopotential field, the estimates cited in the table must be regarded primarily as an illustration of quality of the prognostic model.

Table 1

Mean Estimates of Geopotential Field Based on Series of Forecasts

Изобарическая поверхность, мб 1	Срок прогноза, сут 2				
	1	2	3	4	5
1000	$\frac{0,75}{0,53}$	$\frac{0,81}{0,42}$	$\frac{0.85}{0,40}$	$\frac{0,88}{0,38}$	$\frac{0.88}{0,41}$
850	$\frac{0,77}{0,52}$	$\frac{0.78}{0,49}$	$\frac{0,79}{0,49}$	$\frac{0.85}{0,49}$	$\frac{0.83}{0,49}$
700	$\frac{0,75}{0,54}$	$\frac{0,78}{0,53}$	$\frac{0.78}{0,58}$	$\frac{0.77}{0.64}$	$\frac{0.81}{0,65}$
500	$\frac{0,63}{0,71}$	$\frac{0,69}{0,69}$	$\frac{0,73}{0,69}$	$\frac{0,77}{0.64}$	$\frac{0,87}{0,65}$
300	$\frac{0,63}{0,76}$	$\frac{0.67}{0,72}$	$\frac{0,72}{0,70}$	$\frac{0.74}{0,74}$	$\frac{0.77}{0,72}$
200	$\frac{0,64}{0,77}$	$\frac{0.68}{0,74}$	$\frac{0.70}{0,74}$	$\frac{0.74}{0,75}$	$\frac{0,76}{0,72}$
100	$\frac{0,64}{0,75}$	$\frac{0.68}{0,71}$	$\frac{0,72}{0,83}$	$\frac{0.76}{0.73}$	$\frac{0,77}{0,71}$

KEY:

1. Isobaric surface, mb
2. Time of forecasts, days

An analysis of the results of the computations shows that the proposed model is adequately effective and can be used as one of the modules in a more complete model of atmospheric dynamics.

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MODELING OF HYDROSTATICITY OF LARGE-SCALE ATMOSPHERIC PROCESSES

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[Article by Candidate of Physical and Mathematical Sciences V. M. Kadyshnikov, USSR Hydrometeorological Scientific Research Center, submitted for publication 28 April 1978]

Abstract: A solution of the linear problem of characteristic oscillations of a neutrally stratified atmosphere with respect to adiabatic processes on a rotating plane with periodic initial conditions is described by confluent hypergeometric functions. The dependence of the frequencies of wave oscillations on their length is determined. It is shown that allowance for the influence of turbulent mixing has the result that in long waves, in contrast to short waves, a hydrostatic and quasigeostrophic balance is rapidly established.

[Text] The hydrostaticity of large-scale atmospheric processes is a well-known fact [1], that is, in the third equation of motion the term with vertical acceleration is approximately two orders of magnitude less than each of the two other terms in this equation. It is used constantly by meteorologists in their practical work, in particular, in formulating hydrodynamic weather forecasting models. However, until now there has evidently been no discussion in the literature as to how precisely this important condition is satisfied, that is, whether initially arbitrary disturbances will become hydrostatically adapted and how. Below, using a simple linear hydrodynamic model of the atmosphere it will be demonstrated that an adequate condition for the modeling of hydrostaticity is allowance for the turbulent dissipation of energy.

We use the following concepts as a point of departure. The atmospheric disturbances arising under the influence of different factors can be any arbitrary disturbances allowed by the particular model. Accordingly, solving the problem as a problem with initial data without taking the mentioned factors into account, we must assume that these data are completely arbitrary. In the absence of dissipative factors, the energy of the disturbances is maintained and there is no energy exchange between types of disturbances in the linear model. If it is found that the combined effect of dissipative factors extinguishes the energy of any one type of disturbances considerably more rapidly than the energy of others, it is natural to assume that in such a model in most cases this type of disturbances will virtually never be observed. Then, if the disturbances not filtered out by dissipation have some property, this property will be characteristic of the model in general.

According to [6], small atmospheric oscillations on a plane, superposed on a state of rest, are described by the following linear equations:

$$\begin{aligned} u_t &= -p_x + lv, \\ v_t &= -p_y - lu \\ w_t &= -p_z - g\rho, \\ \rho_t &= -u_x - v_y - w_z, \\ p_t &= -\Gamma w - c^2(u_x + v_y + w_z), \end{aligned} \qquad (1)$$

where u, v, w are $\bar{\rho}u^*$, $\bar{\rho}v^*$, $\bar{\rho}w^*$; $\bar{\rho}$ is the density of the fundamental state (its pressure and temperature are $\bar{p}$, $\bar{T}$; all these three functions are dependent only on z), and u^*, v^*, w^* are components of the velocity vector along the x, y, z axes; p and ρ are the deviations of pressure and density from the values of the fundamental state; l is the Coriolis parameter, assumed to be constant, g is the acceleration of free falling,

$$c^2 = \varkappa \frac{\bar{p}}{\bar{\rho}},$$

$\varkappa$ is the ratio of heat capacities, the stability parameter is $\Gamma = \varkappa R(\gamma_a - \bar{\gamma})$, R is the gas constant, γ_a is the dry adiabatic vertical temperature gradient, $\bar{\gamma} = -d\bar{T}/dz$.

We will study disturbances periodic in horizontal coordinates. Two conditions must be set for the vertical coordinate. The first is obvious: at the underlying surface $w^* = 0$, that is

$$w = 0 \text{ when } z = 0. \qquad (2)$$

We will set the second boundary-value condition proceeding on the basis of the following considerations. As demonstrated in [6], it follows from equations (1) that

$$E_t = -(pu^*)_x - (pv^*)_y - (pw^*)_z, \qquad (3)$$

where

$$E = \frac{u^2 + v^2 + w^2}{2\bar{\rho}} + \frac{1}{2\bar{\rho}c^2}\left[p^2 + \frac{g}{\Gamma}(p - c^2\rho)^2\right]. \qquad (4)$$

This means that if the requirement $w^*p = 0$ at the upper boundary of the atmosphere is joined to condition (2), that is

$$\frac{wp}{\rho} = 0 \quad \text{when} \quad z \to \infty, \tag{5}$$

we will have the energy conservation law in the form

$$\frac{\partial}{\partial t} \iint_D \int_0^\infty E\,dx\,dy\,dz = 0 \tag{6}$$

(D is the periodicity region in horizontal coordinates). From the initial data it is natural to require that

$$\iint_D \int_0^\infty E\,dx\,dy\,dz < \infty. \tag{7}$$

It is found that this same condition with $t > 0$ is completely equivalent to condition (5), at least for isothermic and polytropic fundamental atmospheric states, because for both these states the conditions of limitation of energy and its conservation have the very same solutions. On this basis, as the upper boundary-value condition we take (5).

The solution of the formulated problem, as in [2, 6], will be sought in the form of elementary oscillations

$$f(x, y, z, t) = \tilde{f}(z) \exp i\,(k_x \cdot x + k_y \cdot y - \lambda t), \tag{8}$$

where f is any of the functions u, v, w, ρ, p, since the coefficients of the equations and the boundary-value conditions are dependent only on z. We will examine only "physical" solutions of this type, that is, such that each of them can exist separately, at the same time satisfying both the above-mentioned physical conditions: nonpenetration through the underlying surface and energy limitation.

The problem of finding the frequencies λ and the amplitudes $\tilde{u}$, $\tilde{v}$, $\tilde{w}$, $\tilde{\rho}$, $\tilde{p}$ (henceforth the wavy line will be omitted) in dependence on the wave number

$$k = \sqrt{k_x^2 + k_y^2}$$

has been repeatedly examined in the literature in a study of different problems. For example, in [6] a study was made of oscillations of the isothermic atmosphere and the spectrum of oscillations could be divided into gravitational and acoustic parts. In [2], without taking the Coriolis parameter into account, the results were generalized for the case of an arbitrary temperature stratification. But to a considerable degree they are qualitative.

We will limit ourselves to a study of the characteristic oscillations in a very simple atmospheric model -- neutrally stratified relative to adiabatic processes (oscillations of the type (8) in a still simpler model --

isothermic according to the terminology adopted above -- are not physical). An analytic solution, which in this case is obtained easily, is then used in studying the processes of adaptation of arbitrary large-scale disturbances of meteorological fields to hydrostatic disturbances, taking turbulent mixing into account.

For solving the problem we substitute the functions (8) into equations (1) and we will exclude all the amplitudes, other than pressure. In a neutrally stratified atmosphere $\Gamma = 0$. We will introduce another new independent variable

$$s = c^2(z) = \varkappa R(\overline{T}_0 - \gamma_a z) \equiv s_0 - s_1 z. \tag{9}$$

Then we obtain the equation

$$s^2 p'' - \frac{g}{s_1} sp' + \left[-\frac{k^2 \lambda^2}{s_1^2 (k^2 - l^2)} s^2 + \frac{\lambda^2}{s_1^2} s + \frac{g}{s_1} \right] p = 0,$$

where the prime designates differentiation for s. In the derivation of this equation it was assumed that $\lambda^2 \neq 0$, l^2. It is easy to confirm that the value $\lambda = 0$ is a solution of our problem, but $\lambda = \pm l$ is not.

Since, in accordance with (9),

$$\frac{g}{s_1} = \frac{1}{\varkappa - 1},$$

that is, is not a whole number, the solution of this equation, satisfying condition (5), with an accuracy to a constant factor, has the form [4]

$$p = \alpha_s^b e^{-\frac{\alpha_s}{2}} \Phi\left(\frac{b}{2} - \beta, b, \alpha_s\right), \tag{10}$$

where

$$\alpha_s = \frac{2\lambda k}{s_1 \sqrt{k^2 - l^2}} s, \quad \beta = \frac{\lambda \sqrt{k^2 - l^2}}{2ks_1}, \quad b = \frac{g}{s_1}, \tag{11}$$

and the confluent hypergeometric function $\Phi(r, m, x)$ [7], known also as the Kummer function, is determined by the following series:

$$\Phi(r, m, x) = 1 + \sum_{n=1}^{\infty} \frac{r(r+1)\ldots(r+n-1)}{m(m+1)\ldots(m+n-1)} \cdot \frac{x^n}{n!} \tag{12}$$

(Pohhammer series), convergent everywhere, if m is not a whole negative number. With $s = 0$ $\alpha = 0$, the series also becomes equal to 1. Making use of this fact, it is easy to check that condition (7) is satisfied for each solution.

For this purpose from system (1) it is necessary to express all the functions through p and in accordance with the determination (4) obtain the form of E; we obtain the integral for the restricted region $0 \leqslant s \leqslant s_0$ from the everywhere restricted function. Since the parameter

$$b = \frac{1}{\varkappa - 1} \approx 2{,}5$$

(that is, is not a whole negative number), the series (12) and, therefore, the solution (10) is the analytical functions of all its arguments [7]. The parameters α and β are dependent on λ and k. Therefore, the lower boundary value condition (2), in this case having the form

$$\Phi\left(\frac{b}{2} - \beta,\ b,\ \alpha\right) = \left(1 - \frac{2\beta}{b}\right) \Phi\left(\frac{b}{2} - \beta + 1,\ b + 1,\ \alpha\right),$$
$$(\alpha = \alpha_s|_{s=s_0}) \qquad (13)$$

makes it possible for each k value to find all the λ values.

It follows from conditions (2), (5) and (7) that all λ are real numbers. Omitting the demonstration, we also note that with the exception $\lambda = 0$ all $|\lambda| > 1$.

In some special cases, to wit: a) $\alpha, \beta \ll 1$, b) $\beta \gg \alpha$, 1, c) $\alpha \gg \beta$, 1 are the roots of equation (13) and are easily found by using asymptotic representations of the Kummer function [7]. In a general case they must be determined numerically. The practical computations are facilitated by the fact that the Kummer function at the left in (13) and the function associated with it on the right are analytical, and when

$$\beta = \frac{b}{2} + n$$

the Pohhammer series (12) is transformed into a finite sum.

In the case a) we use the series (12) directly. Neglecting small values, we obtain

$$\beta = \frac{b}{4(b+1)}\alpha. \qquad (14)$$

In the case b), using the corresponding asymptotic formulas [7], we obtain

$$\delta \operatorname{tg} \delta = -\alpha \quad (\delta = 2\sqrt{\alpha\beta}). \qquad (15)$$

This formula can be still further simplified by writing as follows:

$$\delta = n\pi, \qquad (16)$$

where n is a whole number.

In case c) using another asymptotic form [7], we obtain

$$\beta = \frac{b}{2} + n - \varepsilon \quad \left(\varepsilon = \frac{\alpha^{2n+b}\, e^{-\alpha}\, 4^{n+1}}{\sqrt{\pi}\,(2n-1)!\ (2n+3)}\right), \qquad (17)$$

where n is a whole number.

It is possible to proceed from the dependence $\beta = \beta(\alpha)$. In actuality, in accordance with the notations (11),

$$\lambda = \sqrt{\frac{s_1}{H}\alpha_1^2}, \quad k = \frac{\alpha}{2H}\sqrt{1 - \frac{Hl^2}{s_1\alpha_1^2}},$$

where

$$H = \frac{s_0}{s_1} = \frac{\gamma_0}{\gamma_1}$$

is the altitude of the neutrally stratified atmosphere. (Hence, incidentally, with (14) taken into account, it can be seen that it is necessary to examine only

$$\alpha \geqslant 2l\sqrt{\frac{H\varkappa}{g(\varkappa - 1)}} \approx 0{,}02).$$

In particular, the three cases considered above in new variables correspond to: a) low-frequency long waves with the dependence

$$\lambda = \pm\sqrt{gH\frac{\varkappa - 1}{\varkappa}}\sqrt{k^2 + l^2} \tag{18}$$

in place of (14); b) high-frequency long waves with the dependence

$$\lambda = \pm\frac{\pi n}{2}\sqrt{\frac{g(\varkappa - 1)}{H}} \tag{19}$$

in place of (15); c) high-frequency short waves with the dependence

$$\lambda = \pm\sqrt{gk[1 + 2(\varkappa - 1)(n - \varepsilon)]} \tag{20}$$

in place of (17). In expression (17) for ε it is necessary to assume α = 2kH, so that waves not longer than 50-70 km satisfy the assumption $\alpha \gg 1$.

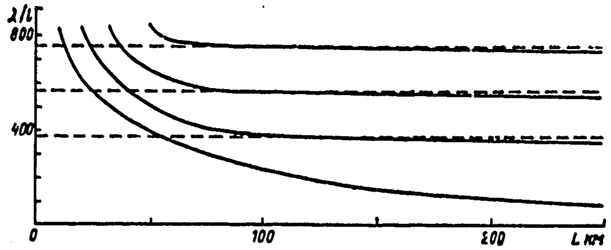

Fig. 1. Dependence of frequency of oscillations on wavelength.

Figure 1 shows the numerically computed dependence of the ratio $\lambda/l > 0$ on wavelength

$$L = \frac{2\pi\sqrt{2}}{k}.$$

The dashed lines represent the asymptotes

$$\frac{\lambda}{l} = \frac{n\pi}{2l}\sqrt{\frac{g(\varkappa - 1)}{H}}.$$

Computations, in particular, confirm the good accuracy of the asymptotic formulas (18)-(20).

It is of interest to compare the constructed spectrum of oscillations with the spectrum of oscillations also of a neutrally stratified, but quasistatic atmosphere [3]. There are five solutions:

$$\lambda = 0, \lambda = \pm\sqrt{R\overline{T}_0 k^2 + l^2},$$

$\lambda = \pm \ell$; the latter are expressed only in the velocity field. First, we see that the value $\lambda = 0$, corresponding to geostrophic disturbances, is a solution in both cases. Second, since

$$gH \frac{\varkappa - 1}{\varkappa} = R\overline{T}_0,$$

the low-frequency long waves with the frequency (18), being external acoustic waves, are also solutions in both cases. However, high-frequency oscillations with frequencies (19) and (20), being internal acoustic waves, were transformed into internal waves with frequencies $\lambda = \pm \ell$ and with a pressure amplitude equal to 0. Formally this transition can be traced as follows. Substituting the functions (8) into equations (1), we supply the frequency λ in the third equation of motion by the factor δ, that is, the transition to quasistatics will correspond to the transition $\delta \to 0$. All the results will remain in force, but in place of the first two formulas (11) we obtain

$$\alpha_s = \frac{2\lambda k\sqrt{\delta}}{s_1\sqrt{\lambda^2 - l^2}} s, \quad \beta = \frac{\lambda\sqrt{\delta(\lambda^2 - l^2)}}{2ks_1}.$$

It therefore follows that formula (14) and the formula (18) which follows from it remain unchanged, that is, the external acoustic waves have the same frequency as in the full equations. At the same time, in the case $\beta > \alpha$, 1 with $\delta \to 0$ $\lambda \to \infty$, that is, there are no such oscillations, whereas in the case $\alpha \gg \beta$, 1 with $\delta \to 0$ $\lambda^2 \to \ell^2$; expression (10) in this case shows that $p \to 0$.

We will apply the results to a study of the problem of a change in the frequency spectrum under the influence of turbulence. We will take into account vertical turbulent mixing occurring primarily in the lower atmosphere -- in the planetary boundary layer, and horizontal turbulent mixing. We will begin with the first. There are different ways to take into account the friction of air against the earth. As in [3], we will do this by the method indicated in [5]. In accordance with this method, all the equations in the model remain the same as without friction, and are assumed to describe the processes adequately everywhere. But at the lower boundary of the atmosphere we stipulate a non-zero vertical velocity, taken from the upper boundary of the Ekman boundary layer, which is assumed to be drawn out into a film. The magnitude of this velocity is given by the known Dyubyuk formula [5]

$$w = \frac{K}{l}(p_{xx} + p_{yy}),$$

and $K = 1.4 \cdot 10^2$ m. Using expressions (8), we obtain hence in place of the boundary value condition (2) the following condition for amplitudes:

$$w = -\frac{Kk^2}{l}p. \tag{2'}$$

Thus, our model now consists of the system of equations (1) with the boundary value conditions (2'), (5) and condition (7) for the initial data. It therefore follows that the solution, as before, is given by formula (10), but from (2') we now obtain, for determining λ as a function of k, the equation

$$\Phi\left(\frac{b}{2}-\beta,\ b,\ \alpha\right) = \frac{l\left(1-\frac{2\beta}{b}\right)}{l + iKk\sqrt{\lambda^2 - l^2}}\,\Phi\left(\frac{b}{2}-\beta+1,\ b+1,\ \alpha\right), \tag{13'}$$

Hence it follows directly that not one of the frequencies λ (other than the values $\lambda = 0$, as before, being a solution), since $\lambda^2 > l^2$, can now be real, because in accordance with (11) this would mean that α and β, and therefore, in accordance with (12), the Kummer function at the left and the function associated with it on the right, are also real; therefore, at the left in (13') there would be a real expression, and at the right -- a complex expression. Then, on the basis of (2') and (3) in place of (6) we have

$$\frac{\partial}{\partial t}\iint_D\int_0^{\infty} E\,dx\,dy\,dz \leq 0,$$

because, for example,

$$\int \frac{K}{l} p_{xx}\,p\,dx = \frac{K}{l}\int [(pp_x)_x - (p_x)^2]\,dx \leq 0$$

with periodic conditions. This means that all the solutions are now attenuating. Now we will convince ourselves that the mechanism of this attenuation is such that long acoustic waves attenuate rapidly in contrast to quasigeostrophic and some acoustic waves attenuating slowly.

For our purposes, obviously, it is sufficient to examine how the asymptotic formulas (18)-(20) change if equation (13) is replaced by (13'). Omitting the computations, we will cite the results.

In the case a) $|\alpha|, |\beta| \ll 1$ in place of equation (14) we have

$$\beta = \frac{b}{4(b+1)}\alpha - i\frac{b}{2}\cdot\frac{Kk}{l}\sqrt{\lambda^2 - l^2}.$$

Hence, for determining λ we obtain a cubic equation accurately coinciding with the equation for the similar problem in a quasistatic case [3]. Its approximate solutions are

$$\lambda_1 = -iK\frac{k^2 gl}{gH\frac{\varkappa-1}{\varkappa}k^2 + l^2} \tag{21}$$

and

$$\lambda_{2,3} = \lambda_0 - iK\frac{k^2 g}{2l\lambda_0^2}\cdot gH\frac{\varkappa-1}{\varkappa}k^2, \tag{18'}$$

where λ_0 is given by formula (18). The solution (21) corresponds to quasigeostrophic waves and (18') corresponds to external acoustic waves. In order to characterize the intensity of attenuation we will take, for example, a wave with a length of 4,500 km. Then the lifetime $\tau = 6.3$ days for a quasigeostrophic disturbance and $\tau = 0.4$ day for external acoustic waves. We note that formula (21), in contrast to (18) and (18'), is also correct for short waves.

In the case b) $|\beta| \gg |\alpha|$, 1 we obtain

$$\lambda = \lambda_0 - iK \frac{g(\varkappa - 1)}{2l} k^2,$$

where λ_0 is given by formula (19). For a wave with the length 4,500 km $\tau = 0.9$ day, that is, long internal acoustic waves attenuate somewhat more slowly than external acoustic waves, but far more rapidly than quasigeostrophic waves.

In the case c) $|\alpha| > |\beta|$, 1 we obtain

$$\lambda = \lambda_0 - i\varepsilon \frac{2K \frac{k^2}{l} g(\varkappa - 1)}{1 + \left(Kk \frac{\lambda_0}{l}\right)^2}, \tag{20'}$$

where λ_0 is given by formula (20). The presence of the factor e^{-2kH} for the fictitious part shows that short internal acoustic waves attenuate very weakly. If, for example, $L = 30$ km, then $\tau > 100$ days.

A similar problem in a quasistatic case [3] has six solutions: $\lambda = 0$, the values (21) and (18'), and also $\lambda = \pm l$. As we now see, a quasistatic approximation, virtually not distorting stationary, quasigeostrophic and external acoustic waves, filters out the internal acoustic waves, adding in place of them standing waves with the frequencies $\lambda = \pm l$.

Now we will proceed to an analysis of the role of horizontal turbulent mixing in the considered model of the atmosphere and we will show that under its influence, first, the disturbances attenuate with a velocity dependent little on their type, and second, the long-wave disturbances attenuate far more slowly than long acoustic waves under the influence of vertical turbulent mixing. This is a very important circumstance and shows that under the influence of vertical turbulence a quasigeostrophic and hydrostatic balance is established at long waves. If it appeared that the little-selective influence of horizontal turbulence is appreciably stronger than the selective influence of vertical turbulence, the fact of a more rapid attenuation of some types of oscillations in comparison with others under the influence of this latter does not have any importance.

In [6] the assumption was made that allowance for the forces of horizontal turbulent viscosity, that is, the addition of Laplacians of the corresponding components of the velocity vector to the three equations of motion, leads to the attenuation of free oscillations with a logarithmic decrement νk^2 (ν is the coefficient before the Laplacian). It is clear that such a result would be obtained rigorously only in a case if the Laplacian of the corresponding functions was added to each of the five equations. Allowance only for viscosity or joint allowance for viscosity and heat conductivity, with the result that the system of equations (1) is replaced by the equations

$$\begin{aligned} u_t &= -p_x + lv + \nu\Delta u, \\ v_t &= -p_y - lu + \nu\Delta v, \\ w_t &= -p_z - g\rho + \nu\Delta w, \\ \rho_t &= -u_x - v_y - w_z, \\ p_t &= -\Gamma w - c^2(u_x + v_y + w_z) + \nu\Delta(p - c^2\rho) \end{aligned}$$

(the viscosity and thermal conductivity coefficients are considered equal) should, in general, lead to a different result. And in actuality, again assuming that $\Gamma = 0$ and making computations, similar to the preceding ones, it can be demonstrated that the amplitude, as before, is determined by formula (10), but the first two formulas (11) have the form

$$\alpha = \frac{2k(\lambda + i\nu k^2)}{s_1\sqrt{(\lambda + i\nu k^2)^2 - l^2}}\,s, \quad \beta = \frac{\lambda\sqrt{(\lambda + i\nu k^2)^2 - l^2}}{2ks_1} \tag{11'}$$

and the dependence $\lambda(k)$ is determined by the transcendental equation

$$\Phi\left(\frac{b}{2} - \beta,\ b,\ a\right) = \frac{l\left(1 - \frac{2\beta}{b}\right)}{l + iKk\sqrt{(\lambda + i\nu k^2)^2 - l^2}} \times \\ \times \Phi\left(\frac{b}{2} - \beta + 1,\ b + 1,\ a\right). \tag{13''}$$

Now we will note the following. For long waves the difference between these formulas and (11) and (13) is small. Therefore, it is possible to investigate the role of the parameters K and ν separately, assuming their total contribution to be additive. We will not do this for short waves, but in this case the problem is easily solved even without such an assumption.

We will begin with long waves. The influence of K has already been investigated. We will clarify the role of horizontal turbulence, solving equation (13) with the notations (11').

In the case a) $|\alpha|, |\beta| \ll 1$ we have equation (14), from which follows the cubic equation

$$\lambda\left[(\lambda + i\nu k^2)^2 - l^2\right] - (\lambda + i\nu k^2)\,gH\,\frac{\varkappa - 1}{\varkappa}\,k^2 = 0,$$

the approximate solutions of which are

$$\lambda_1 = -i\nu k^2 \tag{22}$$

and

$$\lambda_{2,3} = \lambda_0 - i\frac{\nu k^2}{2}, \qquad (18'')$$

where λ_0 is given by formula (18). If it is assumed, as is usually done, that $\nu = 10^6$ m^2/sec and we again examine a wave with the length 4,500 km, the intensity of attenuation of quasigeostrophic disturbances (λ_1) is determined by the value $\tau = 3.0$ days, and external acoustic waves -- $\tau = 5.9$ days.

In the case b) $|\beta| > |\alpha|$, 1 we have equation (16), from which follows the quadratic equation

$$\lambda(\lambda + i\nu k^2) - \frac{n^2\pi^2}{4} \cdot \frac{g(\varkappa - 1)}{H} = 0,$$

the approximate solution of which is (18''), but λ_0 is given by formula (20).

The case c) $|\alpha| > |\beta|$, 1 is not possible at long waves.

Now we will proceed to an analysis of short waves. On the other hand, we have only the case c). From (11') and (13''), using the corresponding asymptotic form [7], we obtain

$$\beta = \frac{b}{2} + n - \varepsilon\frac{l + iKk(\lambda + i\nu k^2)}{l - iKk(\lambda + i\nu k^2)},$$

and the small ε parameter is given by formula (17), and $\alpha = 2kH$. If $\varepsilon = 0$, then

$$\lambda_0 = -i\frac{\nu k^2}{2} \pm \sqrt{2kg(\varkappa - 1)\left(\frac{b}{2} + n\right) - \left(\frac{\nu k^2}{2}\right)^2}, \qquad (23)$$

and with ε taken into account, we obtain

$$\lambda = \lambda_0 - \varepsilon kg(\varkappa - 1)\frac{\dfrac{l^2 - (Kk)^2\, 2kg(\varkappa - 1)\left(\dfrac{b}{2} + n\right)}{\sqrt{2kg(\varkappa - 1)\left(\dfrac{b}{2} + n\right) - \left(\dfrac{\nu k^2}{2}\right)^2}} + 2iKkl}{l^2 + 2Kkl\dfrac{\nu k^2}{2} + (Kk)^2\, 2kg(\varkappa - 1)\left(\dfrac{b}{2} + n\right)},$$

where λ_0 is given by formula (23). With $\nu = 0$ we have formula (20'). In particular, we see that attenuation under the influence of vertical turbulent mixing, due to the simultaneous presence of horizontal turbulence, became still less (in the denominator of the last formula the second term is proportional to ν). Thus, the principal effect on short waves is exerted by turbulent mixing. It is unimportant whether reference is to formula (23) or formula (22); it is easy to check that the corresponding frequency for any k is also a solution.

With respect to long-wave disturbances, as we see, vertical turbulent mixing, exerting virtually no influence on quasigeostrophic waves (with L = 4,500 km the lifetime $\tau = 6.3$ days and due to horizontal turbulence

τ = 3.0 days), rapidly extinguishes acoustic disturbances (τ = 0.4 and 0.9 day respectively for external and internal waves, whereas due to horizontal turbulence τ = 5.9 days).

Thus, turbulence ensures hydrostaticity and quasigeostrophicity of long-wave disturbances in a neutrally stratified atmosphere. It can be demonstrated that the situation is also the same in a stably stratified atmosphere.

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AUTOMATIC CONTROL OF DATA FROM TEMPERATURE SOUNDING OF THE ATMOSPHERE FROM METEOROLOGICAL SATELLITES

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[Article by Professor L. S. Gandin and V. P. Tarakanova, Main Geophysical Observatory, submitted for publication 26 April 1978]

Abstract: The authors have evaluated the possibilities of different methods for automatic control (checking) of data from temperature sounding of the atmosphere from meteorological satellites. It is shown that on the average not less than 7-8% of the telegrams with data from indirect sounding contain serious errors. For detecting and eliminating these errors it is feasible to use statistical horizontal and vertical control methods, somewhat modified by taking into account the correlation of random errors. As a result of this correlation the sensitivity of the considered methods proves to be quite high, despite the great dispersions of the random errors.

[Text] For many years data from temperature sounding of the atmosphere from meteorological satellites have been disseminated on a routine basis. However, attempts at the use of this information together with ordinary radiosonde data in constructing initial fields for numerical forecasting for the most part have led to disappointing results: forecasts with the use of data from indirect sounding have, on the average, been no better than without such use. As a result, up to the present time data from indirect sounding have not yet been included in the operational lines for the routine processing of aerological information at the world prognostic centers, including at the USSR Hydrometeorological Center.

One of the reasons for such a situation, in all probability, is as follows. In the process of collecting, processing and moving any information through communication channels there will inevitably be individual serious errors which must be detected and corrected, or as a minimum, the erroneous data must be discarded. This is the objective of methods for automatic control (checking) with use of an electronic computer, to which, in particular, radiosonde data are subjected routinely [1, 5]. However, applicable to data from indirect sounding not only are automatic control methods not employed, but there has been virtually no discussion of the problem of creating such methods.

In an early stage in the development of indirect sounding the routinely disseminated information on the vertical profiles of temperature and geopotential more or less uniformly covered the earth's surface and an appreciable part of this information was for the region of land covered by data from ordinary radiosonde observations. However, during recent years there has been routine transmission of satellite sounding data only over the oceans and seas, where there were few radiosonde data. Under such conditions the principal means for checking data from indirect sounding is not their comparison with data from direct sounding, but a checking of their internal consistency.

One of the methods for such checking could be statistical checking (control), which is used extensively applicable to radiosonde data. It involves, as is well known (for example, see [4]), a checking of satisfaction of the equations of statics (barometric formula for relative geopotential) in each layer between two adjacent main isobaric surfaces, and specifically, computation of the nonclosures β_i of the equation of statics using the formulas

$$\beta_i = H_{i+1} - H_i - A_i - B_i (t_i + t_{i+1}), \qquad (1)$$

where i is the number of the isobaric surface, H is geopotential gp dam, t is temperature, °C, A_i and B_i are constants:

$$A_i = 1842 \lg \frac{p_i}{p_{i+1}} \text{ gp dam}; \qquad B_i = 3{,}372 \lg \frac{p_i}{p_{i+1}} \frac{\text{gp dam}}{^\circ\text{C}} \qquad (2)$$

In addition to individual serious errors, the β_i nonclosures are caused by always existing small random measurement errors and also by the deviation of the vertical temperature profile in the layer from a linear profile relative to the pressure logarithm. Therefore, the hypothesis of the presence of serious error arises only when β_i in absolute value exceeds some admissible nonclosure Δ_i whose value has been estimated in advance.

Analyzing in such cases the distribution of nonclosures β_i in adjacent layers, most commonly it is possible to ascertain the cause and magnitude of the serious error and introduce the corresponding correction.

Table 1 describes the results of static checking of 912 telegrams with indirect sounding data for 20 July 1974 reaching the USSR Hydrometeorological Center. [These data were put at our disposal through the kindness of Ya. M. Kheyfets.] Each telegram contained data on temperature at 15 surfaces from 1000 to 10 mb and on the relative geopotential of all surfaces above 1000 mb.

Table 1 shows that about 8% of all the telegrams contain serious errors detected by static checking (static checking (control) is not capable of detecting all serious errors). This percent is appreciably lower than for radiosonde data, but it goes without saying that it is impossible to neglect such a number of errors. We also see that more than 70% of the detected serious errors can be corrected without ambiguity using static control, and another 10% by means of a simple combination of static control with some other method.

Unfortunately, beginning in July 1977 the data from indirect sounding, transmitted on a routine basis, do not contain information on temperature, but only include relative geopotential. This deprives the users of the possibility of extremely convenient detection and elimination of serious errors in this information by means of static control.

Another widely used method is horizontal static control. This involves optimum interpolation horizontally to the point to be checked on the basis of data for surrounding points and comparison of the interpolated and observed values. In this case the admissible nonclosure is assumed to be proportional to the mean square error in the mentioned comparison, which is computed in the process of determining the interpolation weights [1, 3].

In evaluating the possibilities of horizontal statistical control of data from indirect sounding it must be taken into account that the random errors of these data, first of all, substantially exceed the average errors of radiosonde data, and second, in contrast to the latter, are horizontally correlated.

The problem of the magnitude of random error in indirect sounding is now quite clear: data from many authors ([7, 11] and others) indicate an agreement with one another that the mean square errors in data from indirect sounding are approximately twice greater than in the case of direct sounding. For example, for the temperature in the troposphere the estimates are 2-3° in comparison with 1-1.5°C for radiosonde observations.

It is understandable that this fact reduces the possibilities of horizontal checking of indirect sounding data.

The situation is different with the correlation of satellite sounding errors horizontally, or to be more precise, along the satellite flight trajectory. The ideas of different authors with respect to the reason for this correlation and information on the correlation functions of errors are contradictory. At the same time, the fact of the presence of correlation of indirect sounding data, which was not given due attention over a series of years, now is generally recognized. This can be judged from a series of studies by Soviet and foreign authors, such as [7, 9, 10]; the correlation of errors is traced to distances comparable to the correlation radius of temperature itself.

Table 1

Results of Static Checking of Indirect Sounding Data

	Количество телеграмм 1		
		в процентах к числу 2	
		всех телеграмм 3	сомнительных телеграмм 4
5 Всего телеграмм	912	100	
6 Сомнительные данные	69	7,6	100
7 Однозначное исправление	50	5,5	72
8 Двузначное исправление	7	0,8	10
9 Более сложные ошибки	12	1,3	18

KEY:

1. Number of telegrams
2. In percent of number of...
3. all telegrams
4. questionable telegrams
5. All telegrams
6. Doubtful data
7. Unambiguous correction
8. Ambiguous correction
9. More complex errors

The correlation of random errors does not decrease, but on the contrary, increases the possibilities of the detection of serious errors against their background, that is, the possibilities of horizontal checking. In this detection process it is desirable to use not optimum interpolation, but optimum comparison, that is, determine the interpolated weights a_i from the requirement of a minimum of the dispersion of error in comparison of the interpolated value and the observed value, and not with the true value. With correlated observation errors these two requirements lead, generally speaking, to different values of the weights. (In such detection it is desirable to use not the optimum interpolation procedure, but optimum (in a statistical sense) comparison).

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Assume that f_i is the observed deviation of the meteorological element from the mean value at the i-th point:

$$\tilde{f}_i = f_i + \delta_i, \tag{3}$$

where f_i is the true value and δ_i is the observation error and assume that the errors correlate with one another but do not correlate with the true values. Then the covariations

$$\tilde{m}_{ij} = \overline{\tilde{f}_i \tilde{f}_j}; \quad m_{ij} = \overline{f_i f}; \quad n_{ij} = \overline{\delta_i \delta_j} \tag{4}$$

(the line designates statistical averaging) are related by the expression

$$\tilde{m}_{ij} = m_{ij} + n_{ij}. \tag{5}$$

The dispersion

$$E^2 = \overline{(\hat{f}_0 - f)^2} \tag{6}$$

of the interpolation error at the point 0 in accordance with the formula

$$\hat{f}_0 = \sum_{i=1}^{n} a_i f_i \tag{7}$$

is then expressed by the formula

$$E^2 = m_{00} - 2\sum_{i=1}^{n} a_i m_{0i} + \sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j \tilde{m}_{ij}, \tag{8}$$

and the dispersion

$$\tilde{E}^2 = \overline{(\hat{f}_0 - \tilde{f}_0)^2} \tag{9}$$

of the error in comparison of the interpolated value with the observed value -- by the formula

$$\tilde{E}^2 = \tilde{m}_{00} - 2\sum_{i=1}^{n} a_i \tilde{m}_{0i} + \sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j \tilde{m}_{ij}. \tag{10}$$

Therefore, with stipulated weights a_i the E and $\tilde{E}$ values are related by the expression

$$\tilde{E}^2 = E^2 + n_{00} - 2\sum_{i=1}^{n} a_i n_{0i}. \tag{11}$$

showing, in particular, that a positive correlation between observation errors ($n_{0i} > 0$) leads, all other conditions being equal, to a decrease in dispersion of the comparison error.

The requirement of an E minimum leads to a system of equations for determining the weights

$$\sum_{j=1}^{n} a_j \tilde{m}_{ij} = m_{0i}, \tag{12}$$

and the requirement of an $\tilde{E}$ minimum leads to the system

$$\sum_{j=1}^{n} a_j \tilde{m}_{ij} = \tilde{m}_{0i}, \tag{13}$$

which in the presence of correlation errors differs from (12). In the control, in contrast to objective analysis, it is desirable to use system (13), which makes it possible to decrease $\tilde{E}$ additionally, that is, increase the sensitivity of the method.

Figure 1 presents some results of numerical experiments carried out with the participation of T. V. Korosteleva for evaluating the possibilities of horizontal control of satellite sounding data in dependence on the distance r between adjacent observation points. This possibility is characterized by a value of the relative comparison error

$$\tilde{\varepsilon} = \frac{\tilde{E}}{\sqrt{m_{0i}}}. \tag{14}$$

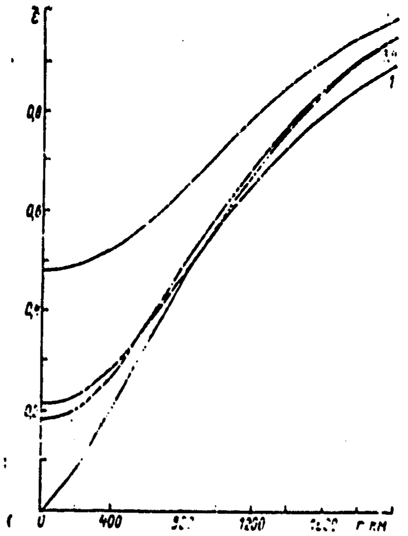

Fig. 1. Dependence of mean square relative error ε in comparison of interpolation value of temperature with observed value on distance r between observation points. 1) $n_{ii} = 2.25\ (°C)^2$, noncorrelated errors; 2) $n_{ii} = 9\ (°C)^2$, noncorrelated errors; 3) $n_{ii} = 9(°C)^2$, correlated errors; optimum interpolation; 4) $n_{ii} = 9(°C)^2$, correlated errors, optimum comparison

Curve 1 in Fig. 1 describes the possibility of checking of radiosonde data ($\sqrt{n_{ii}} = 1.5°C$), and curves 2-4 — data from indirect sounding ($\sqrt{n_{ii}} = 3°C$) in cases of absence of correlation of errors (curve 2) and its presence:

with the use in the computations of the weights of system (12) (curve (3) and system (13) (curve 4). A comparison of the latter with curve 1 shows that the sensitivity of horizontal control of satellite data is somewhat higher ($\bar{\varepsilon}$ is less) than for radiosonde data in the case of small distances r and approximately the same in the case of large r. The possibilities of this control would be decreased somewhat in the case of use of system (12) and would be greatly decreased if the random errors of indirect sounding are uncorrelated with one another.

Table 2

Correlation (Above Diagonal) and Covariation (Below Diagonal, dam^2) Matrices of the Relative Geopotential for Winter Season

1 Слои, мб	1000/850	850/700	700/500	500/400	400/300	300/200	200/100
1000/850	8,94	0.88	0,72	0,60	0,51	−0,16	−0,41
850/700	8,71	10,97	0,91	0.73	0,59	−0,23	−0,57
700/500	10,49	14,67	23.84	0,91	0,76	−0,21	−0,64
500/400	5,36	7,17	13,07	8,84	0,89	−0,16	−0,70
400/300	4,67	6,00	11,46	8,18	9,50	0,14	−0,60
300/200	−1,64	−2,73	−3,57	−1,67	1,48	12,46	0,62
200/100	−10,70	−10,29	−27,12	−17,99	−16,11	19,05	75,21

KEY:
1. Layers, mb

Table 3

Parameters of Vertical Control of Relative Geopotential for Winter Season

Параметр 1	Вариант 2	3 Слои, мб						
		1000/850	850/700	700/500	500/400	400/300	300/200	200/100
$a_{i-1,i}$	а) a	—	0,51	0,79	0,32	0,91	0.80	1,41
	б) b	—	0,49	0,79	0,32	0,83	0,57	1,13
	в) c	—	0,52	0,81	0,33	0,94	0,81	1,40
$a_{i+1,i}$	а)	0,78	0,38	0,81	0,44	0,22	0,41	—
	б)	0,73	0,36	0,66	0,38	0.17	0,60	—
	в)	0,78	0,37	0,82	0,44	0,26	0,40	—
Δ_i	а)	4,0	2,8	3,9	2,8	4,0	5,3	17,9
	б)	4,9	4,0	6,5	4,2	5,4	5,4	20,4
4 (дам^2)	в)	4,2	2,8	4,0	2,9	3,7	5,4	18,6

KEY:
1. Parameter
2. Variant
3. Layers, mb
4. dam^2

Due to the impossibility of static checking, it is accordingly desirable to use the statistical method for checking indirect sounding data by means of vertical interpolation. Applicable to radiosonde data, such a method was proposed by M. I. Yudin [8] (also see [16]).

It is most desirable to use this approach in checking the values of the relative geopotential (thickness) of the layers between the adjacent main isobaric surfaces

$$h_i = H_{i+1} - H_i. \tag{14'}$$

The information on the statistical relationship between the values of the relative geopotential h of different layers necessary in carrying out such checking can be obtained easily on the basis of available data on the interlevel temperature correlation. Precisely from the barometric formula for relative geopotential (compare (1) and (2) we derive the expression

$$m_{ik}^{(h)} = B_i B_k \left(m_{ik}^{(t)} + m_{i,\,k+1}^{(t)} + m_{i+1,\,k}^{(t)} + m_{i+1,\,k+1}^{(t)}\right), \tag{15}$$

where

$$m_{ik}^{(h)} = \overline{(h_i - \overline{h}_i)(h_k - \overline{h}_k)}$$

and

$$m_{ik}^{(t)} = \overline{(t_i - \overline{t}_i)(t_k - \overline{t}_k)}$$

are the covariations of relative geopotential of "elementary" layers and the temperature of the isobaric surfaces respectively and B_i are coefficients determined using formula (2).

As an example, in Table 2 we have given the values m_{ik}^{h}, computed using data from V. P. Boltenkov on the interlevel correlation of temperature for the winter season ([2], see also [5]). Since the relative geopotential is proportional to the mean temperature of the layer, it is characterized by a greater vertical statistical cohesiveness than the temperature of the isobaric surfaces. This can be judged by comparing the values of the correlation coefficients:

$$\mu_{ik}^{(h)} = \frac{m_{ik}^{(h)}}{\sqrt{m_{ii}^{(h)}\, m_{kk}^{(h)}}}, \tag{16}$$

cited in Table 2 above the main diagonal with the data published by Boltenkov on $\mu_{ik}^{(t)}$ [2, 5].

It is desirable that the vertical control of relative geopotential be accomplished by means of interpolation using data from two adjacent layers -- above and below that being checked, and for the extreme layers -- by means of extrapolation using data for one adjacent layer. As in the case of horizontal checking, it is desirable to use an optimum comparison.

As an example, Table 3 gives the results of computation of the interpolation weights $a_{i-1,i}$ and $a_{i+1,i}$ and the admissible nonclosures

$$\Delta_i = k\tilde{E}_i \qquad (17)$$

of such control on the basis of data on the covariations h from Table 2. In these computations the dispersions of errors in determining h_i were computed using the formulas

$$n_{ii}^{(h)} = B_i^2 (n_{ii}^{(t)} + n_{i+1,\,i+1}^{(t)}). \qquad (18)$$

The results of the computations are given for the following variants:
a) for radiosonde data; in this case for the 1000 mb surface it is assumed that $n_{11}^{(t)} = 5(°C)^2$, and for the remaining surfaces $n_{ii}^{(t)} = 1.5(°C)^2$ ($i \neq 1$); the errors were considered uncorrelated, that is $n_{ij}^{(h)} = 0$;
b) for data from indirect sounding; $n_{11}^{(t)} = 16(°C)^2$ $n_{ii}^{(t)} = 6.25(°C)^2$ ($i \neq 1$) with uncorrelated errors $n_{ij}^{(h)} = 0$;
c) for data from indirect sounding with correlated errors, such that

$$n_{i-1,\,i}^{(h)} = n_{i,\,i+1}^{(h)} = 0{,}60 \quad \text{and} \quad n_{i-1,\,i+1}^{(h)} = 0{,}20.$$

In the computations it was assumed that $k = 2.5$ (compare [5]).

The data in Table 3 lead to the conclusion that in the absence of correlation between the errors the possibilities of vertical control of data from satellite sounding on relative geopotential would be far lower than for radiosonde data, but as a result of the correlation of errors of indirect sounding the possibilities of vertical checking of both types of information approximately coincide and are considerable.

Specifically, the admissible nonclosures of vertical checking of data from satellite sounding on relative geopotential decrease due to the correlation of random errors by a factor of more than 2, as can be seen from a comparison of the Δ_i values in lines b) and c). An exception is the extreme layers (in our case 1000/850 and 200/100 mb), the possibilities of whose checking, naturally, are not great. With respect to a comparison of the Δ_i values in lines a) and c), it shows that the admissible nonclosures of vertical checking of data from indirect sounding are even somewhat less than in the case of direct sounding.

The weights and admissible nonclosures cited in Table 3 can also find direct use in developing a routine method for the checking of data from indirect sounding of the atmosphere.

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ACTIVITY OF THE HURRICANE SEASON IN THE NORTH ATLANTIC

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[Article by V. A. Vetroumov, Odessa Hydrometeorological Institute, submitted for publication 1 March 1978]

Abstract: It is proposed that the activity of the hurricane season in an oceanic region be characterized by a complex of quantitative values: intensity coefficient K, mean seasonal velocity of movement of tropical cyclones V, and also their total internal energy U. These characteristics were computed for the period 1886-1974 for the tropical and temperate zones of the North Atlantic. The mean values and variability of K, V, U agree well with unidirectional climatic variations over the northern hemisphere.

[Text] A great many studies [1-6, 9-11] have been devoted to all possible aspects of development of tropical cyclones (TC): frequency of recurrence, movement, cloud and internal structure, energetics and theoretical investigations. However, the activity of individual TC and the hurricane season in general have not been adequately discussed. The qualitative characteristics "intensive," "active" [11], etc. used earlier in different descriptions were ambiguous.

Therefore, our objective was at least a partial discussion of the problem of activity of the hurricane season, to find quantitative values of this activity, and also to ascertain the possibility of using information from TC for describing the peculiarities of the tropical zone and the thermodynamic processes transpiring in it over a long series of years.

It is known that the existence of TC is associated with an entire complex of necessary and for the time being still not thoroughly studied adequate conditions in the ocean and atmosphere [5, 6]. On the basis of regular observations for each oceanic region we registered information, in the form of the number of TC, their trajectories and other characteristics, on the realization of the necessary and adequate conditions for their existence in the ocean-atmosphere system.

As the meteorological-oceanographic conditions accompanying the formation of TC, the authors of [2] used the turbulent transfer of latent heat of condensation Q_c, the turbulent heat flux into the atmosphere from the ocean surface Q_t, and also the realization of the latent heat of condensation A. All these parameters are considered to be the result of interaction between the ocean and the atmosphere and a TC is regarded as the result of this process. Taking into account the conclusion in [2] that the values of the mentioned parameters before and in the period of formation of TC differ considerably (by an order of magnitude or more) from the "quiet" state of the atmosphere, it is possible to speak of the existence of TC as some optimum in the thermodynamic state of the ocean-atmosphere system.

The great variability in the number of TC from year to year [1, 3, 6, 10, 11] makes it possible only in general features to formulate a hypothesis concerning the value to be assigned to this optimum, realized in powerful atmospheric eddies, and on the intensity of such a realization.

The intensity of an individual TC at the present time is evaluated on the basis of the pressure at its center, maximum wind velocity, duration of persistence of these extremal conditions, and finally, on the basis of the economic and human losses caused by them. The intensity of the entire hurricane season is judged, for example, on the basis of the total number of TC and their number reaching the hurricane stage. However, it is not difficult to compare these characteristics and they are not exhaustive for analysis of either an individual TC or for the entire hurricane season.

The application of a simple method to already existing information on TC makes it possible to obtain an index of hurricane intensity which can be used in characterizing individual TC and hurricane seasons in different oceanic regions. We propose that this index be expressed by the ocean area S_{TC} over which existed a TC determined from the length L of the trajectory and the zone affected (diameter D) by the TC:

$$S_{TC} = LD.$$

This area during the season related to the ocean area S_o, such as the North Atlantic, will give the dimensionless coefficient

$$K = S_{TC}/S_o,$$

showing over what part of the ocean region the necessary and adequate conditions were realized during the course of the season.

The length L of the trajectories for all TC in the North Atlantic during the period 1886-1977 in the stages of a tropical storm (TS) and hurricane (Hr) was determined using the materials contained in [10, 11]) and differing

Table 1

Characteristics of Intensity of Hurricane Season in North Atlantic (1886-1974)

	Максимум из средних 1	Минимум из средних 2	Среднее многолетнее 3	σ	V,
4 *Коэффициент интенсивности (K)*					
10 Весь регион	0,92	0.03	0,39	0,19	0,48
11 Южнее 30° с. ш.	1,24	0,02	0,39	0,21	0,55
12 Севернее 30° с. ш.	0,90	0.00	0,38	0,21	0,56
5 *Средняя скорость движения ТЦ (V км/ч)*					
Весь регион	33,4	14,3	22,9	3,7	0,16
Южнее 30° с. ш.	30,8	12,0	19,1	3,3	0,17
Севернее 30° с. ш.	54,2	10,1	30,8	7,4	0,24
6 *Суммарная внутренняя энергия ТЦ за сезон (U·10²⁶ эрг)*					
Весь регион	670,0	24.4	258.6	125,0	0,48
Южнее 30° с. ш.	538,4	12.2	173.0	92,6	0,54
Севернее 30° с. ш.	192,5	0,00	85.6	47,8	0,56
7 *Суммарная внутренняя энергия ТЦ за сезон на м² Северной Атлантики (U·10¹⁴ эрг/м²)*					
10 Весь регион	20,2	0.7	7,8	3,8	0,48
Южнее 30° с. ш.	29,4	0.7	9,5	5,1	0,54
Севернее 30° с. ш.	12,9	0.0	5,8	3,2	0,56
8 *Суммарная внутренняя энергия за сезон на м² площади, над которой существовали ТЦ (U·10¹⁵ эрг/м²)*					
10 Весь регион	3.2	1,4	2.0	0.3	0,16
11 Южнее 30° с. ш.	3.8	1.5	2.5	0.4	0,17
12 Севернее 30° с. ш.	4,5	0.0	1.6	0.5	0,33
9 *Суммарная кинетическая энергия, генерируемая ТЦ за сезон (U·10²⁶ эрг)*					
Весь регион	16.1	0.6	6.2	3,0	0,48
Южнее 30° с. ш.	12.9	0.3	4.2	2,2	0,54
Севернее 30° с. ш.	4.6	0.0	2.1	1,2	0,56

KEY:

1. Maximum of means
2. Minimum of means
3. Long-term mean
4. Intensity coefficient (K)
5. Mean velocity of movement of TC (V km/hour)
6. Total internal energy of TC during season ($U \cdot 10^{26}$ erg)
7. Total internal energy of TC during season per m^2 in North Atlantic ($U \cdot 10^{14}$ erg/m^2)
8. Total internal energy during season per m^2 of area over which TC existed ($U \cdot 10^{15}$ erg/m^2)
9. Total kinetic energy generated by TC during season ($U \cdot 10^{26}$ erg)
10. Entire region
11. To south of 30°N
12. To north of 30°N

with respect to reliability and systematization in accordance with a unified method. A joint allowance for the extent of the trajectories in the storm and hurricane stages was made by us taking into account that the Q_c, Q_T and A values during the pre-hurricane period corresponded to their values in a mature hurricane [2].

The choice of the mean diameter of a TC was complicated due to the different method for evaluating its boundaries (on the basis of the diameter of continuous cloud cover, on the basis of the last closed isobar, on the basis of the determined minimum wind speed, on the basis of the diameter of the rain zone [3, 4, 6] etc.). However, theoretical investigations of Atlantic hurricanes, agreeing with the results of measurements in nature, make it possible to validate this choice [5, 9].

For an "average tropical cyclone" the radius, equal to 2° of meridian, is determined as the distance to which cyclonic circulation is propagated [5].

V. V. Shuleykin [9] estimates the radius of a "standard" hurricane at 225 km. It serves as the outer boundary of a sort of "hurricane nucleus," playing a decisive role in all the energetics of the system. The region over the overheated ocean surface with such a radius is a real heater of a heat engine of the fifth kind, the cooler for which is all the space surrounding the hurricane system [9].

Considering the results of the investigations reported in [5, 9], we decided that the diameter of an "average tropical cyclone" would be equal to 4° of meridian.

If the area of the North Atlantic S_0 is assumed to be bounded by the latitudes 10 and 50°N, and in longitude by 20 and 100°W, it measures $3.32 \cdot 10^{13}$ m^2 and will reflect the real boundaries of existence of a TC in this region. The tropical part of this region from 10 to 30°N and the zone from 30 to 50°N will be equal to $1.83 \cdot 10^{13}$ m^2 and $1.49 \cdot 10^{13}$ m^2 respectively. In the computations of these areas we took into account the changes of map scale with latitude.

As a result we obtained the coefficients of intensity of hurricane seasons K for the North Atlantic as a whole and separately for the zones to the south and north of 30°N (Table 1).

It follows from Table 1 that in the secular variation K varies in the range from 0.03 to 0.92. For the tropical part it varies from 0.02 to 1.24, and in the temperate latitudes from 0.0 to 0.84. In a single year (1933) of the 89 years which we considered the area of the ocean over which TC existed exceeded the area of the tropical part (to the south of 30°N). During this year the intensity coefficient was 1.24 and the number of TC was the maximum (21) for the entire observation period. Despite this, K for the temperate zone (30-50°N) in 1933 (0.53) only somewhat exceeded the mean long-term value (0.38).

The variability of K (with respect to the standard deviation σ and the relative variability V_σ), considerable in magnitude, is approximately identical for the tropical and temperate zones of the region and is somewhat less for the entire North Atlantic.

The great activity of the hurricane seasons in 1887, 1893, 1933, 1953 and 1958, noted in [10, 11], found its reflection also in the quantitative K values: 0.82, 0.85, 0.92, 0.72 and 0.64 respectively.

A weakening of activity of the hurricane season in 1970 and 1972 [11] was accompanied by a decrease in the number of TC and their intensity coefficients; the latter were more than three times less than their mean long-term value: 0.11 and 0.12.

The general direct dependence of K on the number of TC is natural, but it does not have a regular nature. For example, for a number of TC equal to 7 (and during the considered period there were 8 such years) the intensity coefficients varied from 0.56 to 0.11. Therefore, it is clear that the climatological characterization of the hurricane season solely on the basis of the number of TC incompletely reflects its peculiarities.

The coefficient K, quantitatively describing the intensity of the hurricane season quite well, is dependent on the total length of the TC trajectories. However, it only indirectly gives some idea concerning the time during which the conditions in the ocean and atmosphere optimum for the life of TC prevail. Determination of this time will undoubtedly refine the characterization of intensity of the hurricane season.

If the length L of the trajectories is related to the time of their existence, it is possible to obtain the mean velocity of movement of TC during the season in the storm and hurricane stages for different parts of the region (Table 1). The maximum mean velocity of TC during the season in the tropics was 30.8 km/hour; the minimum was 12.0 km/hour. Our computations confirm the known fact of presence of a great velocity of TC in the temperate latitudes (the maximum of the mean V there is 54.2 km/hour; the minimum is 10 km/hour). The amplitude of the mean velocity in the temperate latitudes, and also its variability, during the considered period is approximately twice as great as in the tropics. The long-term values in the tropical (19.1 km/hour) and the temperate (30.8 km/hour) latitudes reflect the mean velocities of the zone of Trades and westerly transfer.

It is obvious that this characteristic in itself is important and can become a separate theme for investigation.

A deeper understanding of different physical processes arises in an understanding of the energy characteristics associated with them. Therefore, we made an attempt to determine them for the TC for the hurricane season in the considered region. An individual TC could be characterized most completely by the energy balance for the entire volume and during the entire period of its life, and for a season -- by the total indices of the balance components. However, such computations involved enormous difficulties caused both by the inadequacy of meteorological information from ocean areas and by the constantly changing parameters of each TC in the different stages of its existence. At the present-day stage calculations of the energy balance and its individual components for a real TC [2, 4, 5] with a number of boundary conditions is a difficult problem, but it is soluble. Such studies of TC on the basis of data for TC which are 30-40 years old are still more difficult due to the deficiency of meteorological data. Theoretical investigations of an "average tropical cyclone" and the conclusions from them which agree with the characteristics of real TC observed in nature [5, 9] make it possible to determine the mean value of the energy parameters of a TC for a long series of years. Such an assumption involves some percentage of error, but on the other hand it gives some idea concerning the energy level of the TC during the season and its contribution to the total energy of the northern hemisphere. As a result, it will be possible to trace the long-term course of this characteristic in relationship to climatic variations.

The total internal heat source of an "average" TC [5], equal to the outflow of the energy produced in it, is $56.4 \cdot 10^{10}$ kJ/sec or $5.64 \cdot 10^{21}$ erg/sec.

The total power of a "standard" hurricane as a function of the underlying surface of the ocean is assumed to be equal to $2 \cdot 10^{8}$ MV or $2 \cdot 10^{21}$ erg/sec [9]. The close, but lesser than in [5] energy level is probably associated with its computation for a fixed water temperature (28°C) and air temperature (27°C).

In a determination of the "order of magnitude" of the latent heat set free in a TC, a value $2\text{-}4 \cdot 10^{25}$ erg/day was obtained in [6] or $0.23\text{-}0.46 \cdot 10^{21}$ erg/sec, that is, an order of magnitude less than in [5] and [9]. In [6] there was no indication of the dimensions of the TC for which the liberated energy was estimated.

Computations for the real typhoon "Nancy" give a total internal energy for one of the days of $826 \cdot 10^{25}$ erg/day [4] or $9.56 \cdot 10^{22}$ erg/sec, that is, this value exceeds by more than an order of magnitude the levels obtained in 5, 9]. The latter was caused by the radius of the typhoon, greater than 2° of meridian. Near 20°N (where "Nancy" was situated) the mean radius of the TC must be 185 miles [3]. Recalculations of the total internal energy of the typhoon for an area with a radius of 2° in meridian gives a value $10.05 \cdot 10^{21}$ erg/sec, which only exceeds by a factor of 2 the similar energy for an "average" hurricane according to Palmen and Newton [5].

In our calculations for an "average" hurricane with a radius of 2° in meridian we used a total internal energy equal to $5.64 \cdot 10^{21}$ erg/sec. In the opinion of the authors of [5] themselves, this quantity is somewhat (by 10%) too low, but rather fully characterizes an "average" TC. Multiplying this quantity by the total seasonal lifetime of TC in the storm and hurricane stages, we obtained the mean value of the total internal energy of the TC (U) during each year. The mean and extremal U are given in Table 1.

Table 2

Values of Characteristics of Tropical Cyclones in the North Atlantic During Different Climatic Periods (1886-1974)

Период 1	Коэффициент интенсивности сезона ураганов K 2				Средняя скорость движения ТЦ за сезон V, км/ч 3				Суммарный внутренний источник тепла ТЦ за сезон на м² $U \cdot 10^{14}$ эрг/м² 4			
	среднее 5	σ	V_σ	ε	среднее	σ	V_σ	ε	среднее 5	σ	V_σ	ε
	6 *Весь регион*											
1890—1914	0,37	0,20	0,55	0,08	22,0	4,4	0,20	1,8	7,77	4,00	0,52	1,64
1915—1939	0,34	0,19	0,56	0,08	23,0	3,5	0,15	1,4	6,88	4,17	0,61	1,71
1940—1964	0,44	0,15	0,33	0,06	24,4	3,1	0,12	1,3	8,30	2,83	0,34	1,16
1965—1974	0,33	0,15*	0,46	0,11	21,5	2,4*	0,11	1,7	7,18	3,30*	0,46	2,36
1970—1974	0,27	0,14*	0,53	0,17	21,0	2,4*	0,11	3,0	5,94	3,28*	0,53	4,07
	7 *Южнее 30° с. ш.*											
1890—1914	0,39	0,22	0,57	0,09	18,4	3,0	0,16	1,2	9,75	5,25	0,54	2,16
1915—1939	0,39	0,25	0,64	0,10	20,2	4,4	0,22	1,8	9,17	6,02	0,66	2,47
1940—1964	0,40	0,15	0,38	0,06	19,5	2,3	0,12	0,9	9,44	3,61	0,38	1,48
1965—1974	0,28	0,13*	0,48	0,09	17,0	2,5*	0,15	1,8	7,35	3,51*	0,48	2,51
1970—1974	0,25	0,14*	0,53	0,17	17,7	2,8*	0,16	3,5	6,34	3,34*	0,53	4,15
	8 *Севернее 30° с. ш.*											
1890—1914	0,35	0,23	0,65	0,09	30,1	7,6	0,25	3,1	5,34	3,32	0,62	1,36
1915—1939	0,27	0,16	0,60	0,07	31,5	8,4	0,27	3,4	4,08	2,68	0,66	1,10
1940—1964	0,49	0,18	0,38	0,07	32,5	6,2	0,19	2,5	6,83	2,49	0,36	1,02
1965—1974	0,41	0,21*	0,52	0,15	27,4	6,0*	0,22	4,3	6,98	3,84*	0,55	2,75
1970—1974	0,29	0,21*	0,72	0,26	26,4	7,7*	0,29	9,6	5,40	4,48	0,83	5,56

9 * Несмещенная оценка (σ_{n-1})

KEY:

1. Period
2. Coefficient of intensity of hurricane season K
3. Mean velocity of TC movement V during season, km/hour
4. Total internal TC heat source during season per m^2 $U \cdot 10^{14}$ erg/m^2
5. mean
6. Entire region
7. To south of 30°N
8. To north of 30°N
9. Unbiased evaluation (σ_{n-1})

If it is taken into account that TC, in contrast to extratropical cyclones, generate and maintain their characteristic available potential energy due to the setting free of latent heat in the moist air rising from the lower layers, increasable by the flow of latent and perceptible heat from the sea, and also that the liberation of latent heat expended on heating of the upper troposphere constitutes an irreversible process [5], it becomes clear how important it is to examine the problem of TC as an energy redistribution mechanism.

If it is assumed that the efficiency of a heat engine (which a TC is) is 2.4% [5], it is possible to determine the kinetic energy generated (Table 1).

Table 1 shows that the levels of the total internal energy of a TC are subject to great variability ($V_\sigma = 0.48-0.56$). The yield of energy from TC in the tropical zone is twice as great as in the zone 30-50°N. The maximum energy release during a season was observed in 1933 and the minimum was observed in 1914. The total energy yield from TC during the hurricane season from a square meter of area over which TC existed on the average was almost three times greater than the energy which could be assigned to the entire North Atlantic. The variability of this TC index has a rather stable nature: its relative variability for the zone 10-30°N is 0.17; for the temperate latitudes it is 0.33 and 0.16 for the entire region.

Now we will make some comparisons for estimating energy processes in TC.

The mean kinetic energy of the northern hemisphere in summer is approximately $19.1 \cdot 10^{26}$ erg [3]. However, the mean kinetic energy of TC for the North Atlantic for the 89 years which we investigated was $6.21 \cdot 10^{26}$ erg, that is, a third of this energy. We emphasize that it was generated during 53 days -- the average lifetime of TC in the TS and Hr stages. The maximum level of kinetic energy of TC ($16.1 \cdot 10^{26}$ erg) was only somewhat less than its mean value during the northern hemisphere summer. The generation of the kinetic energy of mean meridional circulation in summer in the northern hemisphere is estimated at $1 \cdot 10^{10}$ KW [5] and during the hurricane season (53 days) is approximately equal to ($4.6 \cdot 10^{26}$ erg) its generation in TC (Table 1).

The heat transport by ocean currents in the northern hemisphere, directed poleward, attains a maximum at 20°N: $2.4 \cdot 10^{22}$ cal/year or $2.8 \cdot 10^{26}$ erg/day [8]. During the hurricane season it is $145.8 \cdot 10^{26}$ erg, that is, approximately one-half the mean total yield of energy produced in a TC ($258.6 \cdot 10^{26}$ erg) and is comparable to the heat of TC released in the troposphere between 30 and 50°N ($85.6 \cdot 10^{26}$ erg).

The problem of the methods for atmospheric use of the energy released by the atmosphere is important and remains inadequately studied, although some aspects of this problem were touched upon in a series of studies [5,6]. Directly in the zone 30-50°N the energy of TC is expended on heating of the troposphere and the transformation of atmospheric circulation. The energy of TC in the tropical zone (to the south of 30°N) is transported northward by the mean Hadley circulation and participates in maintaining the intensity of the frontal zone and jet streams over the hemisphere [5].

We have already examined the presence of a good correspondence of TC indices for the North Atlantic and climatic variations on a global scale in part in [1]. The qualitatively new information on the tropical zone in this region obtained above on the basis of the characteristics of TC for a long series of years also makes it possible to compare them with climatic variations for the last century. Taking into account the conclusions in [8] that regional climate is part of its general changes and this is a factor of great importance to be considered, and that the North Atlantic is a sensitive indicator of these climatic changes, we will compare the distribution of the parameters which we obtained -- the intensity coefficient K, the mean velocity of TC V and its total internal energy U -- during different periods of unidirectional climatic variations and in general we will attempt to evaluate its modern trends.

Table 2 gives the mean values and variability of K, V and U during clearly expressed periods of warming (1915-1939) and cooling (1940-1964). As a comparison we have also examined a 25-year period of an insignificant increase in air temperature over the northern hemisphere in the modern period (1965-1974).

For the entire water area of the North Atlantic during the period of cooling there are a maximum intensity of the hurricane season, a maximum mean velocity of movement of TC for all the periods and a maximum value of the released energy. The standard deviation and the relative variability of these characteristics are not only less than their values for the entire series, but also less than in the two preceding 25-year periods. This is evidence of the stability of atmospheric processes forming and determining the existence of TC in an epoch of global cooling.

Warming over the hemisphere was accompanied by K, V, U values close to the mean long-term values, but appreciably smaller than during a cooling. The standard deviation was approximately equal to its value for the entire series, but greater than during cooling. The relative variability of K and U had a maximum value for all the considered periods. In contrast to a cooling, the atmospheric processes determining the existence of TC have an unstable character.

The distribution of the considered TC parameters for the modern period (1965-1974) and especially during the last five-year period (1970-1974) for the entire region of the North Atlantic and its parts has tendencies similar to the warming period (1915-1939). The intensity coefficient for the entire region during the last decade was equal to K for the warming epoch. During the last five-year period, in comparison with the period of cooling, it decreased by approximately 40%. The relative variability of K in the modern period exceeded its value for the cooling epoch by a factor of 1.6 and corresponded to the warming period.

A peculiarity of the distribution of the mean velocity of movement of TC V is an increase in its amplitude between the tropics and the temperate latitudes during cooling and a decrease during warming. A minimum value of the amplitude was noted during 1970-1974. The variability for the entire region during different climatic periods does not have clearly expressed tendencies. However, for zones to the south and especially to the north of 30°N it is easy to trace the correspondence of the maximum σ and V_σ values to the warming period and the minimum values during the cooling period. During the modern period σ and V_σ are closer in value to the warming period.

A decrease in the total internal energy of TC, characteristic of the warming epoch, is clearly traced during the modern period and is accompanied by a considerable increase in the relative variability of this index.

In checking the hypothesis of a statistical significance of the differences in the sample means (Table 2) using the Student test [7], on the assumption that the K, V and U sets almost conform to a normal law, significant differences were obtained in a comparison of the means for the cooling-warming epoch, cooling-last 10 years epoch. This is manifested to a high degree with respect to K and U in the temperate latitudes. The reliability of the substantial difference in mean values was assigned a confidence coefficient 0.95.

The significance of the difference in sample means was also checked by a comparison of their difference with the confidence limit expressing the limits of random variations. The confidence limits of the means (ε) with an evaluation reliability 0.95 are given in Table 2.

Summary

1. As a result of our investigation of TC on the basis of data for many years it was found to be possible to characterize quantitatively the poorly studied activity of the hurricane season by some new parameters: intensity coefficient K, mean velocity of movement of TC V and their mean total internal energy U.

2. Quantitative values of qualitatively new information on the tropical zone of the North Atlantic with respect to the TC characteristics K, V, U, together with the generally accepted parameters, can be used as predictors in the preparation of long-range and background forecasts.

3. Atmospheric processes, favoring the development and existence of TC, during a period of general cooling have a relatively stable character. During a period of warming the relative variability of these processes approximately doubles.

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UDC 551.(465.53:515)(571.6)(265)

CORRELATION BETWEEN CIRCULATION PECULIARITIES OF THE NORTHWESTERN PART OF THE PACIFIC OCEAN AND WEATHER CONDITIONS IN THE SOUTHERN FAR EAST

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 50-55

[Article by V. F. Voronina, Far Eastern Hydrometeorological Scientific Research Institute, submitted for publication 10 April 1978]

Abstract: An attempt was made to explain the variability of weather conditions in the southern part of the Far East on the basis of dynamics of the Kuroshio Current -- the meandering and eddy formation processes. Prognostic relationships are obtained. The conclusion is drawn that there is a need for using satellite information data in developing methods for the long-range forecasting of hydrometeorological phenomena.

[Text] According to modern concepts, for successful prediction of weather it is necessary to take into account circulation in the ocean, processes of interaction between the ocean and the atmosphere. As is well known, in the redistribution of heat on the earth an important role is played by sea currents. They transport enormous masses of heat from one part of the earth to another. The influence which sea currents exert on the climate and weather of the continents has been described in many investigations.

During recent years serious changes have occurred in our ideas concerning the nature of currents in the ocean. The old concept of "smooth" large-scale currents has been replaced by ideas suggesting a system of eddies. A polygon experiment carried out in 1970 by Soviet scientists in the tropical zone of the Atlantic and subsequent investigations [1] indicated that the principal carriers of kinetic energy in the ocean are eddies with motion of water in clockwise (warm anticyclonic) and counterclockwise (cold cyclonic) directions. At each particular moment it is possible to discover an entire series of such eddies in the ocean, different in extent and with different reasons for their appearance.

The study of the physical nature of small- and mesoscale eddy formations in the ocean and their interaction with the surrounding medium is the objective of the joint Soviet-American POLIMODE program. The experiments begun by "Poligon-70" are continuing, but even now our investigations show that the statistical picture of the distribution of eddies in the ocean (in space and in time) varies. Most frequently they are discovered in the region of the main oceanic currents [1, 9, 10]. Here, in addition to small-scale and mesoscale eddies, there are large-scale eddies formed from meanders. The diameter of these large dynamic formations varies from several tens to several hundreds of miles. Warm anticyclonic eddies have a tendency to move northward; cold cyclonic eddies have a tendency to move southward. In the atmosphere such eddies are usually displaced in opposite directions: anticyclonic -- to the south, cyclonic -- to the north. Giant eddies -- circulations, formed from meanders, determine the oceanic conditions over extensive water areas [2, 10].

In order to clarify the role of meandering processes and large-scale oceanic eddies in formation of weather in adjacent regions we carried out a comparison of data on oceanic circulation conditions in the northwestern part of the Pacific Ocean with data on the monthly quantity of precipitation in Primor'ye during the period 1954-1976. Peculiarities of atmospheric processes were not taken into account. It was assumed that the quantity of falling precipitation during the month for the selected territory is an index of various peculiarities of atmospheric processes, in the development of which a significant role is played by thermal conditions in the considered region of the ocean [3, 4, 8].

As is well known [2, 7, 9], the northwestern part of the Pacific Ocean, being a region of interaction between the warm Kuroshio Current and the cold Oyashio Current, differs from the surrounding waters by intensive heat transfer processes and eddy formation on fronts. Here it is common to observe cases of the formation of large-scale eddies from the meanders of the Kuroshio [2, 10, 11]. Several quasistationary regions of current meandering are traced: a curvature of the current in a southerly direction (cyclonic meander) most frequently is observed between 137-140°E, 145-148°E and 152-155°E. The curvature of the current in a northerly direction (anticyclonic meander) most frequently is observed between 141-145°E and 148-152°E.

According to data in [2, 9, 10], the cyclonic eddies formed from the meanders of the Kuroshio have a tendency to be displaced toward the south and southwest, whereas anticyclonic eddies have a tendency to be displaced to the north and northeast. With displacement, under the influence of processes of horizontal and vertical mixing with the surrounding water, the eddies are destroyed. The rate of movement of the eddies, in connection with the specific conditions, varies from 0.5 to 2 miles/day. The lifetime of these circulations is a half-year to a year.

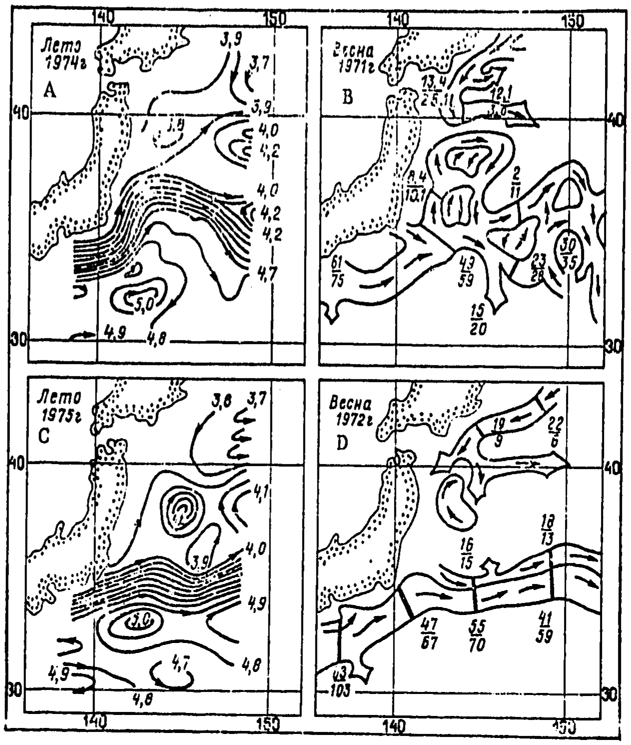

Fig. 1. Dynamic maps of the ocean surface relative to 1000 mb (according to V. P. Pavlychev) (at left) and diagrams of transport of water (numerator, 10^6 m^3/sec) and heat (denominator, 10^{10} Cal/sec) by the Kuroshio Current (reports of the Far Eastern Scientific Research Hydrometeorological Institute) (at right) during period of development (1971, 1974) and destruction of meander and formation of anticyclonic eddies (1972, 1975).

KEY:

A) Summer 1974	C) Summer 1975
B) Spring 1971	D) Spring 1972

Cyclonic eddies exist considerably less time than anticyclonic formations. Anticyclonic eddies are characterized by the greatest frequency of recurrence, intensity and lifetime. These are formed from meanders of the Kuroshio, whose formation occurs in the region 141-145°E. At the beginning the axis of the current in this region forms a slightly expressed anticyclonic curvature to the north. This curvature (meander) gradually increases.

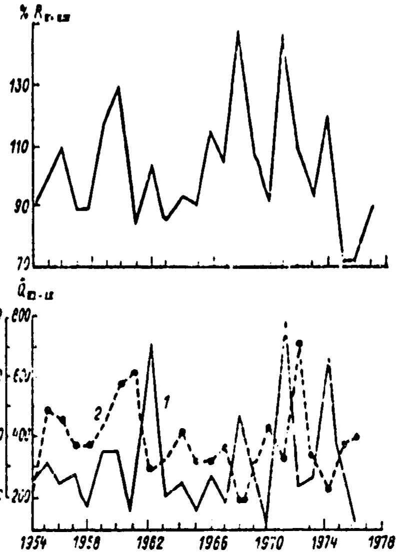

Fig. 2. Long-term course of averaged quantity of precipitation R over Primor'ye area (% of norm) during May-August and mean water discharges Q (June-September) on rivers of Amur region. 1) on Ussuri River (Kirovskiy post), 2) on Bureya River (Kamenka post).

At the base of the meander the distance between the opposite sectors of the Kuroshio is narrowed; an anticyclonic eddy is formed which is later detached from the main Kuroshio Current. The lifetime of the meander from the moment of its appearance to separation of the warm (anticyclonic) eddies, according to the data in [2], is from one to five years.

The degree of development of meandering processes in the considered region is different in different years. Thus, according to the investigations of N. P. Bulgakov [2], V. P. Pavlychev [9] and V. V. Pokudov [11], during the last 20-25 years, according to data which are far from complete (due to the absence of continuous observations), the development of anticyclonic meanders (surges of warm waters) in the region 141-145°E was observed in 1955, 1956, 1959, 1960, 1968, 1971 and 1974. On the other hand, in 1954, 1958, 1966, 1969, 1970, 1972, 1973, 1975-1977 the Kuroshio Current did not have great curvatures. During these years to the north of it there were anticyclonic eddies formed from meanders. The Kuroshio occupied a more southerly position.

An example of a diagram of water transport (m^3/sec) and heat transport (Cal/sec) by the Kuroshio Current in sections in the layer 0-1000 m during the period of development and destruction of an anticyclonic meander and the formation of anticyclonic eddies is shown in Fig. 1. The computations were made in the Division for Study of Hydrological Processes in the World Ocean in the Far Eastern Scientific Research Hydrometeorological Institute on the basis of the results of expeditionary investigations. The dynamic maps were taken from a study by V. P. Pavlychev [9]. Using these maps, constructed on the basis of observations of the density field, it is possible to obtain some idea concerning the streamlines and the velocity of geostrophic currents at any horizon above the zero (reference) surface. In this case as the reference surface the lower observation horizon -- 1,000 m -- was taken.

As we see, the data in the figure graphically show different degrees of meandering of the Kuroshio during different years. In the spring of 1971 the unified Kuroshio flow was observed only to the south of Japan (Fig. 1, at right). To the east of 142°E the current divided into individual branches, forming meanders. The northern branch of the current attained 40°N and at a meridian approximately 145°E turned southward. In the spring of 1972 the Kuroshio did not meander. The summer of 1974 differed from the summer of 1975 by having a surge of warm waters to the north. In 1975 the Kuroshio axis was displaced southward; an anticyclonic eddy was observed to the north of it. During these years a graphic idea concerning the variability of the current position is given by dynamic maps, where the Kuroshio flow is clearly traced from the close spacing of the contours (Fig. 1, at left).

What weather conditions were observed in Primor'ye during the period of development of anticyclonic meanders in the region 141-145°E and during the period of their destruction and the formation of anticyclonic eddies? Taking into account that for processes of interaction between the ocean and the atmosphere the considered region is characterized by asynchronous relationships [3-5, 8] and that the formation of eddies here most frequently occurs at the beginning of spring and at the end of winter [10], for the purpose of obtaining prognostic dependences we used data on the monthly quantity of precipitation during May-August 1954-1976 for 10 stations in Primor'ye. Precipitation was averaged in area.

Figure 2 shows that during periods of development of anticyclonic meandering in the region 141-145°E (see the mentioned years) it was most common to observe an excess of precipitation, whereas during the years of their destruction and the formation of anticyclonic eddies there was a shortage of precipitation and drought. The existence of the detected relationships is also indicated by data on the long-term variation of summer discharges ($\bar{Q}_{VI-IX}$) of water in the rivers of the Amur basin: Ussuri River (Kirovskiy post) and the Bureya River (Kamenka post). During the period of development of a meander the water discharges on the Ussuri River increase by a factor of 2-3 or more, whereas during the period of destruction they drop off. The reverse picture is observed on the left-hand tributaries of the Amur: the greatest water discharges are observed most frequently during the destruction (absence) of meanders in the Kuroshio and the formation of anticyclonic eddies; the minimum discharges are observed during the development of a meander [5].

The physical sense of the determined relationships can be explained in the following way. During a period of development of large-scale anticyclonic meanders (surges of warm waters) in the region 141-145°E the high-altitude frontal zone over the considered region [3] is displaced toward the north. The extent of the Far Eastern high-altitude ridge decreases from south to north during the spring-summer period. The zone of convergence of flow aloft is situated over the Kurile Islands or the Sea of Okhotsk, and therefore the frequency of recurrence of anticyclones of the Okhotsk group increases [4]. In the absence of anticyclonic meanders the frontal zone in the atmosphere over the considered region occupies a more southerly position. In this case the greatest frequency of recurrence of anticyclones is not observed over the Sea of Okhotsk, but over the northwestern part of the Pacific Ocean.

The role of Okhotsk anticyclones in the formation of summer weather over the Far East is well known [6]. With their intensive development, in Primor'ye there is a predominance of moist weather; with weak development there is a predominance of relatively dry weather. In the first case the westerly and southwesterly cyclones, encountering a pressure barrier, become stationary over Primor'ye or regions close to it; in the second case they pass along the Amur basin and more southward of Primor'ye and this causes the noted peculiarities in variation in the quantity of precipitation.

The determined relationships indicate that the peculiarities of development of atmospheric processes over the northwestern part of the Pacific Ocean and the regions adjacent to it are influenced to a considerable degree not only by the "ocean-continent" temperature gradients [12], but also by the temperature contrasts between warm and cold water masses and the localization of this zone of contrasts in space. The sign of the temperature anomaly of surface waters during the period of development (destruction) of a meander and the formation (destruction) of the anticyclonic eddies can be very different. An analysis of the maps of distribution of water temperature anomalies at the ocean surface in the considered region during the summer period 1966-1976 indicated that 1969 and 1971 were extremely cold. In the first case to the east of the Japanese islands there were anticyclonic eddies and the Kuroshio Current occupied a southerly position. In the second case, an anticyclonic meander was observed in the considered region. The subtropical waters, as was noted above (Fig. 1, at right) were propagated to 40°N. The summer of 1968 was extremely warm. The season was characterized by the development of an anticyclonic meander, by the propagation of warm waters to 40°N and northward.

The noncorrespondence between the actual temperature field of the ocean and the distribution of water temperature anomalies is evidently attributable to the fact that the norms available to the researcher in fact are not entirely indicative for evaluating the thermal state of the water masses in this season (month). This problem requires additional investigations.

Our investigations indicate that data on the dynamics of the Kuroshio Current in the region 141-145°E (meandering and eddy formation) give important information for evaluating weather conditions in the future. This requires regular expeditionary observations of the Kuroshio regime.

Recently there has been rapid development of methods for satellite oceanography. Photographs taken from satellites make it possible to see the boundaries of currents (temperature contrasts), cyclonic and anticyclonic meanders and eddies. This means that data from satellites and the determined relationships even now can be used in developing methods for and preparing long-range forecasts of hydrometeorological phenomena.

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UDC 551.510.534

NUMERICAL MODELING OF SYSTEMS FOR OBSERVING AND ANALYZING OZONE FIELD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 56-65

[Article by Candidate of Physical and Mathematical Sciences O. M. Pokrovskiy, Ye. Ye. Ivanykin and A. Ye. Kaygorodtsev, Leningrad State University, submitted for publication 1 June 1978]

Abstract: The authors have formulated the problem of numerical analysis of the ozone field on the basis of the totality of data from ground and satellite observations. The article proposes an algorithm for the recursive assimilation of information supplying optimum statistical evaluations at the points of intersection in a regular grid. Also examined are spatial interpolation schemes, as well as schemes for the smoothing and assimilation of different types of ozone data. A study is made of the spatial structure of evaluation errors. The effectiveness of assimilation of the temperature and ozone fields in the stratosphere on the basis of a combined observation system is demonstrated. The characteristics of accuracy in estimating ozone when using different analytical schemes are presented.

[Text] There are two approaches for attaining a satisfactory accuracy in determining the ozone field. The first involves an increased complication of a satellite experiment program (carrying out combined measurements of the limb, transparency and at the nadir [2]). In this paper we discuss the possibilities afforded by another approach. A refinement of estimates of the three-dimensional ozone field at the points of grid intersection can be accomplished on the basis of realization of recursive procedures of optimum spatial smoothing and assimilation of data from satellite and ground measurements and also the use of additional information from observations of the temperature field. In this case use is obviously made of factual information on the statistical structure of the considered random fields.

Table 1

Examples of Numerical Analysis of Ozone Field

1 Входная информация *							2 Результаты объективного анализа					
							10 общее содержание			11 вертикальное распределение		
3 Схема анализа	4 Номер варианта	5 Регион	6 Точки наблюдений	7 Вид информации	8 Расстояние до узла, км	9 Точка оценивания	σ_ω 10^{-3} см	$\sigma_\omega/\bar{\omega}$ %	$(\hat{\sigma}_\omega/\sigma_\omega)^2$ %	σ_q нб 12	$\sigma_q/\bar{q}$ %	$(\hat{\sigma}_q/\sigma_q)^2$ %
с 13	1	Е	3	с 20	0	3	8,4	2,3	8,5	9,2	15	76
	2	Е 18	4	с	0	4	10,2	2,7	6,4	12,9	25	71
	3	И	1	с	0	1	6,0	2,1	4,7	5,4	16	58
	4	И	2	с	0	2	6,2	2,5	7,0	5,1	13	58
	5	И 19	4	с	0	4	6,9	2,8	12,0	6,8	23	70
	6	И	5	с	0	5	5,1	2,0	5,1	5,6	18	76
	7	И	6	с	0	6	5,3	2,1	12	4,1	13	75
	8	И	3	с	0	3	7,3	3,0	16	6,3	25	74
з 14	1	И	2	н	150	6	12	4,6	64	4,8	16	83
	2	И	2	н 21	780	5	19	7,0	75	7,6	24	85
	3	Е	4	н	190	3	23	7,0	66	11	17	80
	4	И	4	с	690	1	27	9,5	70	8,1	20	87
и 15	1	И	2	н	1710							
		И	6	н	1720	4	11	4,2	29	6,3	20	52
	2	И	2	н	1710							
		И	6	н	1720							
		И	5	н	1360	4	8,9	3,4	20	5,4	17	37
	3	И	2	н	1710							
		И	6	н	1720							
		И	5	н	1360							
		И	1	н	690	4	7,0	2,8	13	3,9	14	22
	4	Е	1	н	1920							
		Е	2	н	910	4	24	7,0	46	13	29	77
	5	Е	1	н	1920							
		Е	2	н	910							
		Е	3	н	190	4	19	5,5	28	10	21	54
	6	И	2	с	1710							
		И	6	•	1720							
		И	5	•	1360	4	14	5,5	50	7,8	25	78
	7	И	2	•	1710							
		И	6	•	1720							
		И	5	•	1360							
		И	1	•	690	4	11	4,5	32	6,6	22	63
сс 16	1	И	1	•	1120							
		И	4	•	1710							
		И	5	•	770							
		И	6	•	150							
		И	2	•	0	2	4,1	1,6	3,4	3,6	9	38
сус 17	1	И	2	н	1120							
		И	1	с	0	1	5,5	1,9	3,4	4,4	12	40
	2	И	2	н	1120							
		И	6	н	1090							
		И	1	с	0	1	3,8	1,2	1,5	3,5	9	28
	3	Е	1	н	1920							
		Е	4	с	0	4	8,6	2,2	3,8	11	20	51
	4	Е	1	н	1920							
		Е	3	н	190							
		Е	4	с	0	4	6,9	1,6	2,2	8,5	16	32

KEY:

1. Input information
2. Results of objective analysis
3. Analytical scheme
4. Number of variant
5. Region
6. Observation points
7. Type of information
8. Distance to point of intersection, km
9. Evaluation point
10. Total content
11. Vertical distribution
12. nb
13. Satellite data
14. Extrapolation
15. Interpolation
16. Smoothing of satellite data
17. Satellite and ground measurements
18. Europe
19. India
20. satellite
21. ground

Note: Numbers of ozone sounding stations: 1 -- Varanasi, 2 -- Akhmedabad, 3 -- Kodaikanal, 4 -- Dum-Duma, 5 -- New Delhi, 6 -- Mont Abu (India); 1 -- Lisbon, 2)-- Mont Louis, 3 -- Arosa, 4 -- Hohenpeisenberg, 5 -- Berlin, (Europe)

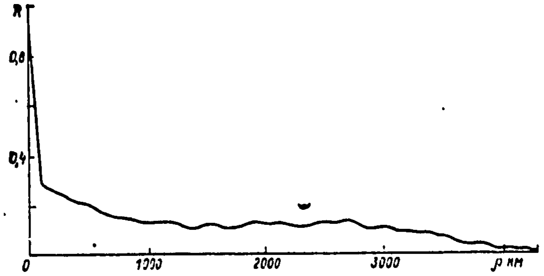

Fig. 1. Latitude component of horizontal correlation function of total ozone content.

Such an approach was recently used successfully in a numerical analysis of main meteorological fields for the purpose of increasing the effectiveness of remote sensing data [1, 5, 6].

Objective Analysis Algorithm

The problem of numerical analysis of the characteristics X of some three-dimensional meteorological field X in a statistical formulation essentially involves a refinement of the a priori evaluation $\bar{X}$, characterized by the empirical covariation matrix Σ, on the basis of use of a set of linearized equations in the form

$$\Delta Y_i = A_i \cdot \Delta x_i + \varepsilon_i \quad (i = 1, \ldots, k), \tag{1}$$

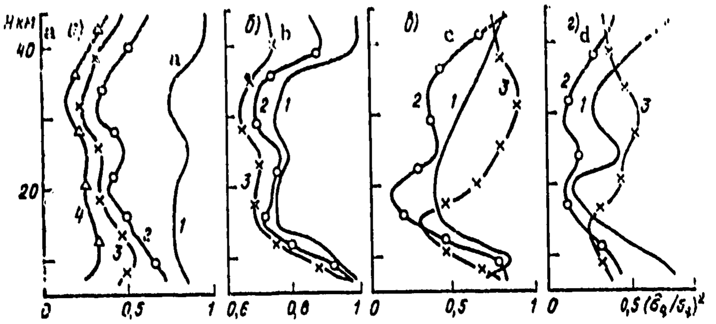

Fig. 2. Vertical distributions of relative residual dispersions. a) analysis of ground observations; b) analysis of satellite observations: 1) extrapolation, 2-4) interpolation using 2-4 points; c) assimilation of satellite observations: 1, 2-4 and 5 point (India), 3-4 point (Europe); d) assimilation of satellite and ground observations: 1, 2 -- ground data at 1 and 2 points (India), 3 -- ground data at 1 point (Europe).

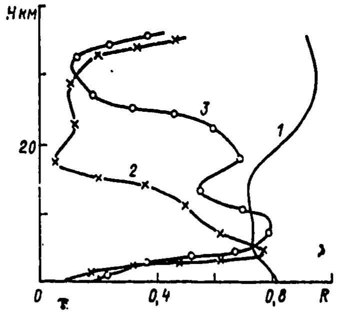

Fig. 3. Profiles of correlation coefficients of spatial relationships of temperature (1), statistical relationships of temperature and ozone concentration (2) and spatial relationships of ozone (3).

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describing the system of observations. Here $\Delta x_i = x_i - \bar{x}_i$ is the vector of deviations of the vertical distribution of the meteorological element from its mean values $\bar{x}_i$ at the i-th geographical point where an observation was made. The matrix operator A_i relates small variations of the vector of the measured characteristics $\Delta Y_i = Y_i - A[\bar{x}_i]$ with the corresponding fluctuations of the parameters to be evaluated Δx_i. Therefore, if $A[x]$ is nonlinear, then

$$A_i = \frac{\partial A}{\partial x_i} [\bar{x}_i].$$

Table 2

Examples of Assimilation of Temperature and Ozone Fields

	Входная информация * 1						2 Результаты объективного анализа					
							9 общее содержание			10 вертикальное распределение		
	3 Схема анализа	4 Номер варианта	5 Точки наблюдений	6 Вид информации	7 Расстояние до узла, км	8 Точка оценивания	σ_ω 10^{-3} см	$\sigma_\omega/\bar{\omega}$ %	$\left(\hat{\sigma}_\omega/\sigma_\omega\right)^2$ %	11 σ_q нб	$\sigma_q/\bar{q}$ %	$\left(\hat{\sigma}_q/\sigma_q\right)^2$ %
12	с	1	1	со 18	0	1	8,5	2,6	3,9	19	28	66
		2	2	со	.	2	9,8	2,9	4,1	21	27	63
13	т	1	1	ст 19	.	1	8,3	2,4	3,6	16	23	50
		2	1	нт 20	.	1	7,8	2,2	3,3	14	20	40
14	нат	1	2	нт	560	1	25	7,3	34	17	26	58
		2	1	нт	560							
			2	нт	0	2	21	6,6	21	14	20	36
		3	2	нт	560							
			1	нт	0	1	13	4,1	11	9	15	23
15	нст	1	2	ст 21	560	1	27	7,8	38	18	27	60
		2	2	ст, со	560							
			1	ст	0	1	21	6,3	24	16	23	48
		3	2	ст, но 21	560							
			1	ст	0	1	15	4,6	12	12	18	30
16	сст	1	1	ст, со	560							
			2	ст, со	0	2	7,7	2,2	3,1	13	18	31
		2	2	ст, со	560							
			1	ст, со	0	1	6,6	2,0	2,4	12	18	30
17	сат	1	1	нт, со	560							
			2	нт, со	0	2	7,1	2,1	2,3	12	16	26
		2	2	нт, со	560							
			1	чт, со	0	1	6,0	1,8	2,2	11	17	27

KEY:

1. Input information
2. Results of objective analysis
3. Analytical scheme
4. Number of variant
5. Observation points
6. Type of information
7. Distance to point of intersection, km
8. Evaluation point
9. Total content
10. Vertical distribution
11. nb
12. satellite ozone sensing
13. information on temperature
14. aerological temperature sounding
15. ozone measurements + satellite data on temperature
16. spatial assimilation of satellite data on ozone and temperature
17. assimilation with use of aerological temperature measurements
18. satellite data on ozone
19. satellite data on temperature
20. ground data on temperature
21. ground data on ozone

Note: Numbers of stations: 1) Hohenpeisenberg, 2) Berlin

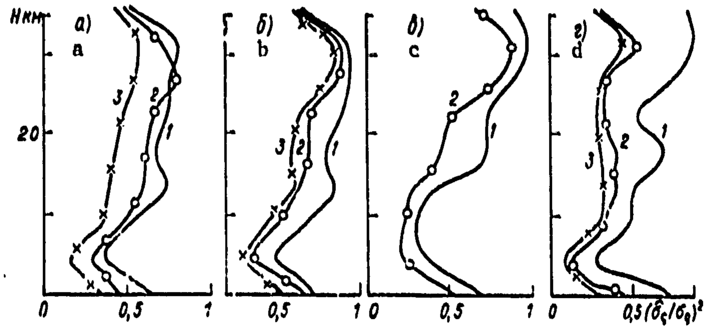

Fig. 4. Assimilation with data on temperature. a) interpolation of aerological data; b) interpolation of satellite data; 1, 2) from one point, 3) from two points; c) assimilation with thermal sounding data at current point: 1, 2) absence and presence of data; d) assimilation with aerological data: 1) absence of data, 2, 3) assimilation at 1 and 2 points

Having empirical statistics, it is possible to define spatial regions lying within the limits of the correlation radius of the random field. We will take one such region G. The objective of this objective analysis is obtaining evaluations of the meteorological elements at the points of intersection of a regular grid. If p is the number of the points of intersection situated in the region G and n is the number of standard vertical levels, then the number of parameters to be evaluated at the grid points of intersection is pn and the total number of components of the combined vector X is equal to r = (k+p)n, which corresponds to data at the grid points of intersection and observation points. The combined vector of the initial data $\Delta Y = (\Delta Y_1^*, \ldots, \Delta Y_k^*)^*$ has the dimensionality s = mk (m is the number of parameters measured at each of k observation points). Having a priori statistics for X, it is possible to compute the corresponding vector of the mean values $\bar{X}$ and the covariation matrix Σ. We rewrite (1) in the form of the matrix equation

$$\Delta Y = A \cdot \Delta X + \varepsilon \qquad (2)$$

relative to the combined vector $\Delta X = X - \bar{X}$. We will examine the structure of (2). The matrix A has the block form $A = (\bar{A} \mid 0)$; the submatrix $\bar{A}$ has a block-diagonal structure

$$\bar{A} = \begin{pmatrix} A_1 & 0 & \ldots & 0 \\ 0 & A_2 & \ldots & 0 \\ \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & \ldots & A_k \end{pmatrix}.$$

The dimensionality of $\overline{A}$ is km x kn. The zero matrix block 0 in A is related to the components of the vector X, corresponding to the data at the points of intersection of a regular grid, and has the dimensionality km x pn.

We will denote the l-th row of the A matrix by a_l. Then system (2) can be rewritten in the form of a set of scalar equations

$$\Delta y_l = a_l \cdot \Delta X + \varepsilon_l \quad (l = 1, \ldots, km). \tag{3}$$

We will assume that the measurement errors ε_l are independent random values with zero means and the dispersion δ_l^2. The principal advantage of (3), distinguishing it from (1), is that (3) contains the combined vector of all the parameters to be evaluated ΔX. Usually in a numerical solution of the objective analysis problem difficulties arise which are related to the need for inversion of poorly stipulated matrices with a great dimensionality [3]. In [4], in order to overcome these difficulties, a block-by-block inversion method is proposed. Below we discuss the possibilities of a recursive evaluation algorithm. Having a system of equations in the form (3), the evaluation algorithm can be written in the form of the following recursive procedure:

$$1)\ X^0 = \overline{X},\ B_0 = \Sigma,\ \Delta X^0 = 0;$$

$$2)\ \Delta X^l = \Delta X^{l-1} + \frac{B_{l-1} \cdot a_l^*}{\delta_l^2 + a_l \cdot B_{l-1} \cdot a_l^*} (\Delta y_l - a_l \cdot \Delta X^{l-1});$$

$$3)\ B_l = B_{l-1} - B_{l-1} \cdot a_l^* \cdot (B_{l-1} \cdot a_l^*)^* / (\delta_l^2 + a_l \cdot B_{l-1} \cdot a_l^*)$$
$$(l = 1, \ldots, km).$$

After s = km recursive algorithm intervals the procedure for evaluating a meteorological field within the limits of the G region is completed. The covariation matrix $\hat{\Sigma} = B_s$ characterizes the accuracy of the evaluations obtained $\hat{X} = \overline{X} + \Delta X^s$. Thus, a realization of the described algorithm in general does not require an inversion of the matrices. The algorithm stability is dependent on to what extent the sum $\delta_{l+1}^2 + a_{l+1} \cdot B_l \cdot a_{l+1}^*$ exceeds 0. In any case

$$\delta_{l+1}^2 + a_{l+1} \cdot B_l \cdot a_{l+1}^* \geqslant \delta_{l+1}^2 > 0.$$

Therefore, the corrections obtained in each algorithm interval have a "smoothed" character. The ratios of the diagonal elements of the covariation matrices $\hat{\Sigma}$ and Σ are the values of the relative residual dispersions (RRD); $(\hat{\sigma}_{ii}^2/\sigma_{ii})^2$ are graphic statistical parameters characterizing the effectiveness of numerical analysis at the points of grid intersection.

Modeling of Ozone Observation Systems

On the basis of the results of measurements from surface ozone sounding stations [9], which we regard as the points of intersection in a horizontal grid, we computed the first and second moments of the random three-dimensional ozone field. In this case it is necessary to have information not only on the total content, but also on the vertical ozone profile. Therefore, there was a possibility of using data for only two groups of stations (India -- 6 stations, Europe -- 5 stations). We used samples consisting of 60 realizations (records) (for each of the considered stations) and relating to the spring period of 1969-1972 [9].

The structure of the vectors to be evaluated X is characterized by the dimensionality n = 10. The first component is the total content ω(m atm-cm), the nine following components correspond to the vertical distribution q (nb) at a particular observation point.

Now we will discuss methods for stipulating the specific form of the operators A_i. In the case of ground measurements the role of the indicated operator is played by the unit matrix I. We will assume that satellite measurements are made at the nadir using a three-channel IR spectrometer (ozone absorption band 9.6μm, centers of intervals: 1045, 1055, 1065 cm^{-1}, spectral resolution $\Delta\nu = 5$ cm^{-1}). The elements of the matrix operator A_i are computed in accordance with the scheme presented in [2], on the basis of the corresponding mean profiles $\overline{q}$. The random observation errors ε were modeled, proceeding on the assumption that the levels of errors in ground observations are $5\cdot10^{-3}$ cm for ω, 3 nb for q, and the errors in satellite spectrometer measurements are 1 erg/($cm^2\cdot sec\cdot sr.cm^{-1}$).

In the course of an analysis of the computation results we discovered a similarity of two statistical characteristics: the correlation coefficient between ω and q, and also the relative residual dispersion for the remote sounding method. It can therefore be concluded that data from satellite nadir measurements for the most part contain information on the total ozone content. A more precise determination of the vertical distribution of q is accomplished by means of a q-ω regression.

Figure 1 shows the smoothed dependence of the horizontal correlation function of the total ozone content obtained on the basis of processing of data for 46 stations in the northern hemisphere [9].

Numerical Models for Spatial Analysis

Information on the spatial statistical structure of the ozone field make it possible to use more complex analytical models for the interpolation, smoothing and assimilation of elements not only for the vertical, but also for the horizontal components. The results of these computations are presented in Table 1 in a uniform form. The table gives the absolute and relative errors and also the RRD of the ω and q estimates. The characteristics relating to q were averaged for h.

First we will discuss optimum interpolation, the need for which arises when there is a noncoincidence of the points of intersection in the regular grid and the observation points. We will discuss the accuracy in determining ozone on the basis of the remote method directly at the observation point (analytical scheme c). In this case the error in evaluating ω is equal to

$(5-10)\cdot10^{-3}$ cm, which is a relative error of 2-3%. The RRD of the evaluations are 5-15%. For the q profile the similar characteristics fall in the range 5-20 nb, or 10-25%, and the RRD of the evaluations are 60-80%. Thus, the relative errors in determining the q profile exceed by an order of magnitude the errors in evaluations of the total content. The simplest interpolation method is extrapolation from the observation point to the closest point of intersection in the grid (scheme э). The data for variants э - 1, 2, 3 make it possible to note the low accuracy in estimates of the total content, even when using data from ground measurements. The determination errors increase less appreciably. However, the RRD of the estimates exceed the 80% level. In the case of extrapolation of data from satellite measurements the errors in the estimates are still greater (э - 4). The RRD values for q are 85-90%. Comparison of the э variants 1, 2 makes it possible to note a dependence of the extrapolation error on distance.

Optimum interpolation (scheme u) ensures a significant increase in analytical accuracy (Fig. 2a,b). With an increase in the number of points at which ground observations were made (u - 1-5), it is possible to increase the analytical accuracy by a factor of 1.5-2. The absolute values of the errors for the European region are somewhat greater than for the Indian region. Nevertheless, the RRD values are approximately identical for both regions. The data for variants u - 6, 7 indicate a smoothing of the errors in satellite observations when using an optimum interpolation algorithm. In this case the errors in determining ω are equal to $(10-15)\cdot10^{-3}$ cm, which is 3-5%. The errors in evaluating the q profile are 5-10 nb, or 10-25% respectively. A comparison of variants c - 5, u - 6,7 indicates that the interpolation procedure more effectively refines the q profile than ω. A comparison of data for u - 2, 3, 6, 7 leads to the conclusion that the accuracy of analysis on the basis of the results of satellite measurements is 1.5-2 times lower than according to ground observations. We note that the vertical structure of analytical errors varies little with an increase in the number of ground observation points (Fig. 2a) and is smoothed with an increase in the number of satellite measurements (Fig. 2b).

In a case when the system of satellite observations is sufficiently "dense" in horizontal coordinates (relative to a regular grid) an important role must be played by the procedures of spatial smoothing and assimilation. The spatial smoothing of satellite information (scheme cc) ensures an increase in evaluation accuracy (c - 3, cc - 1) of ω and q by 25-30%. The RRD values in this case are reduced by a factor of 1.5. The limited effectiveness of smoothing of errors is evidently attributable to the relatively greater distances between observation points. The vertical structure of errors in this case (Fig. 2c) remains extremely inhomogeneous. For regions having a network of ozone sounding stations the procedures of assimilation of data from satellite and ground measurements (scheme cyc) are of practical importance. An examination of the variants c - 3, cyc - 1,2 indicates that the use of information from ground stations situated at a distance of 1,000 km makes it possible to increase the accuracy of sounding from a satellite by a factor of approximately 1.5-2. The vertical structure of analytical errors is considerably smoothed (Fig. 2d). Somewhat poorer results were obtained for the European region (eye - 3, 4).

The cited research results indicate that information on the statistical structure of the three-dimensional ozone field creates a basis for the effective use of objective analysis procedures for the purpose of reducing observation errors, increasing the value of data from remote sensing, and also for representing the collected information at the points of intersection of a regular grid.

Assimilation of Ozone and Temperature Fields

The low accuracy in determining ozone from satellite measurements dictates the use of additional information. Data from ground observations supply data for only an insignificant part of the earth's surface. On the other hand, already over a period of years a satellite system has been in development for thermal sounding of the atmosphere. Researchers [11] also note the presence of a significant statistical correlation between the distribution of ozone and temperature in the stratosphere. Guided by these prerequisites, we carried out modeling of a combined system of satellite and ground observations of ozone and temperature simultaneously. In this case the components of the vector of parameters to be evaluated were obtained from data on the total content ω, concentration q and temperature T. Only two stations in Europe -- Berlin and Hohenpeisenberg -- had synchronous aerological data of this type.

In the computations we used samples consisting of 60 ozone profiles and 60 temperature profiles for each of the mentioned stations for the spring period 1970-1971 [9]. In an analysis of the system for remote temperature sounding of the stratosphere we used the matrix operator A_1, corresponding to the "weight functions" of the 4-channel SCR satellite IR spectrometer [10]. In the computations it was assumed that the error in spectrometric measurements made for thermal sounding purposes is 1 $\text{erg}/(\text{cm}^2\cdot\text{sec}\cdot\text{sr}\cdot\text{cm}^{-1})$; the error in aerological sounding is 1°C. The errors in measuring ozone were the same as above.

Now we will examine briefly the principal correlation characteristics of the ozone and temperature fields. It can be seen from the data in Fig. 3 that the spatial correlations of the temperature field are the strongest. The cross-correlation of temperature and ozone on the average is 40-50% and is close in structure and value to the spatial correlation for ozone, but is considerably poorer than the temperature correlations.

Several typical situations can arise in the assimilation of ozone and temperature information. We will examine them. The results of numerical modeling are presented in Table 2. The simplest case is when we have information on temperature (scheme T) at a point of intersection in the horizontal grid. It is found that the presence of satellite (T - 1) or aerological

(T - 2) information on the thermal structure of the stratosphere ensures obtaining not less precise (on the average) ozone estimates than on the basis of remote ozone sounding (c - 1). A comparison of curves 2 in Fig. 4a,b with the graphs in Fig. 2c makes it possible to note that the structure of the information obtained on q from the results of temperature sounding differs considerably from that which is characteristic for the ozone remote sensing method. This circumstance serves as an additional basis for the assimilation of both types of measurements.

Now we will examine a case when as the initial information for obtaining an ozone estimate at a grid point of intersection it is possible to use data from aerological sounding of temperature obtained at adjacent meteorological stations (scheme uat). A comparison of the variants T - 2, uat - 1 leads to the conclusion that with a noncoincidence of the temperature observation point with a grid point of intersection the accuracy in estimating ozone decreases considerably. The use of two independent temperature measurements (uaT - 2) and use of ozone measurements (uaT - 3) makes possible a considerable increase in the accuracy of estimating ω and q. In this case the errors are $15 \cdot 10^{-3}$ cm and 10 nb respectively. The vertical structure of analytical errors is quite homogeneous (Fig. 4a).

Now we will discuss the possibilities of use of data from remote temperature sounding for estimating ω and q (scheme ucT). A comparison of the variants uaT - 2, ucT - 1 indicates that the replacement of aerological temperature data by satellite data leads to an insignificant loss in the accuracy of the estimates made. The addition of satellite information on temperature and ozone at an adjacent observation point (ucT - 2) leads to an increase in the accuracy of ω estimates by 20% and q by 10%. The inclusion of data from surface measurements of ozone in combination with satellite information on temperature (ucT - 3) has a more appreciable effect. The homogeneity of the vertical structure of errors in this case is illustrated in Fig. 4b. Thus, in the interpolation of temperature data the accuracy in estimating ozone is $(15\text{-}30) \cdot 10^{-3}$ cm for ω and 10-20 nb for q.

Now we will examine an analytical scheme based on the spatial assimilation of satellite data on ozone and temperature (scheme ccT). In actuality, our comparison of the variants ccT - 1, 2 and c - 1,2 leads to the conclusion that the use of data from remote temperature sounding makes it possible to increase the accuracy in estimating ozone by 20-50%. The corresponding RRD values are reduced by a factor of 1.5-2. However, in this case the vertical nonuniformity of satellite ozone information (Fig. 4c) begins to have an effect to a greater degree than in the situations considered earlier.

Now we will discuss an assimilation scheme with the use of data from aerological measurements of temperature (scheme caT). On the basis of a comparison of caT - 1, 2 and c - 1, 2 we conclude that the use of data from surface temperature observations in a numerical analysis ensures an increase in the accuracy of estimating ω by 20-40% and q by 30-50%. In this case the RRD decrease by a factor of approximately 2, attaining values 10-30%. It should be noted that in multipoint assimilation the replacement of aerological information on temperature by satellite information does not lead to a significant loss in accuracy in estimating ozone (ccT - 1, 2, caT - 1, 2). There is some smoothing of the vertical structure of errors (Fig. 4d) in comparison with the ccT scheme.

Thus, temperature data are an important predictor of the actual ozone distribution in the stratosphere. The use of temperature information (remote or aerological) makes it possible to increase the accuracy in numerical analysis of the ozone field by a factor of 1.5-2.

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EVALUATION OF THE FACTORS FORMING THE MICROCLIMATE OF ALMA-ATA CITY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 66-71

[Article by Candidate of Technical Sciences Kh. A. Akhmedzhanov and V. I. Degtyarev, Kazakh Scientific Research Hydrometeorological Institute, submitted for publication 5 May 1978]

Abstract: On the basis of microclimatic investigations in built-up areas, in streets, at intersections, in open areas and squares and using aircraft sounding of the underlying surface and computations it has been established that one of the principal factors favoring an increase in air temperature on clear days in summer by 8°C and in winter by 10°C in Alma-Ata city in comparison with its outskirts is the fact that the area is built up. Urban microclimate can be regulated to a considerable degree by the rational distribution of green areas, fountains and water surfaces, in combination with the built-up area.

[Text] As a result of the intensive growth of population and the size of cities the changes occurring in their climate are becoming more impressive and appreciable. Large cities, regardless of their latitude and landscape-climatic zones, with respect to their macroclimatic conditions are heat islands [9, 14, 16, 17, 19]; amidst the small cities of the steppe, semidesert and desert zones there are also oasis cities [5]. However, the presence of one heat island over a city is more clearly expressed in cities in plains areas, provided that at the same time they are characterized by a uniformity of built-up areas, a uniformity of green areas, etc.

The microclimate of Alma-Ata is formed under particularly complex orographic conditions [2]. The steppe begins along the northern margin of the city and this steppe undergoes transition into desert; its southern margins come right up to the northern slope of the Zailiyskiy Alatau. On the south, southeast and east the city is framed by hills which rise 400-700 m above the city. In addition, the relief of the city, although uniformly, drops off from south to north with a change in elevation by 200-250 m. Such a combination of relief and the city create a complex structure of interaction of the factors forming microclimate.

The urban built-up area is one of the factors introducing substantial changes in almost all the microclimatic characteristics of this particular city.

Table 1

Distribution of Radiation Temperature (t_{equiv} °C) of Walls of Buildings of Different Orientation by Observation Times for Alma-Ata

Время 1	2 Ориентация стен зданий							
	С 3	СВ 4	В 5	ЮВ 6	Ю 7	ЮЗ 8	З 9	СЗ 10
	Январь 12							
11 9 ч 30 *мин*	3	3	8	11	10	4	3	3
12 30	5	5	6	13	15	11	5	5
15 30	2	2	2	2	2	5	6	5
	Апрель 13							
6 30	4	7	6	3	1	1	1	1
9 30	4	6	12	13	9	4	4	4
12 30	5	5	7	12	12	9	5	5
15 30	3	3	3	3	6	9	10	6
	Июль 14							
6 30	6	11	10	4	2	2	2	2
9 30	5	8	15	16	9	5	5	5
12 30	5	5	8	13	14	10	5	5
15 30	4	4	4	4	9	14	13	7
18 30	0	0	0	0	0	2	2	2
	Сентябрь 15							
6 30	3	7	7	4	1	1	1	1
9 30	4	5	14	17	12	4	4	4
12 30	5	5	7	14	16	11	5	5
15 30	3	3	3	3	6	13	13	8

KEY:

1. Time
2. Orientation of building walls
3. N
4. NE
5. E
6. SE
7. S
8. SW
9. W
10. NW
11. hours...minutes
12. January
13. April
14. July
15. September

In order to make a quantitative estimate of the degree of influence of the factors favoring both an increase and decrease in temperature in the city we carried out computations of the radiation temperatures of wall surfaces, measurements of the temperature of the underlying surface of a city from a sounding aircraft and experimental investigations at fountains, walls of buildings, in squares and streets, at intersections, in green areas and in open spaces in a city. These essentially involved measurement of temperature and air humidity, determination of wind direction and velocity at a height of 1.5 m using MV-4 aspiration psychrometers and MS-13 anemometers.

Computations of the radiation temperature of the wall surface (t_{equiv}) were carried out using actual regime data for scheduled observation times at the Alma-Ata Hydrometeorological Observatory. The computation formulas used were the formulas derived by A. M. Shklover [13], taking into account that for the conditions prevailing in Alma-Ata according to the SNiP (Construction Norms and Specifications) P-A-7-62 the heat transfer coefficient at the surface of a barrier is $a_{obs} = 20$ Cal/($m^2 \cdot °C$) and the coefficient of absorption of solar radiation by the outer surface of a barrier is $P = 0.6$.

With the exposure of a barrier construction to solar radiation the surface temperature of the walls subjected to the insolation during the daytime during the course of the entire year increases by 13-17°C and the temperature of the shaded walls increases up to 6°C as a result of secondary scattering in comparison with the surrounding air (Table 1). K. A. Birskaya and Z. L. Lomtatidze [1], on the basis of field observations and computations for the Tbilisi urban area, drew the conclusion that for surfaces with different orientations the solar irradiation is equivalent to a considerable temperature increase: for the eastern and western walls by 22.4°C, for the southeastern and southwestern walls -- by 20.2°C, for the northern walls -- by 6.2°C, for southern walls -- by 15.4°C, with a maximum (by 27.4°C) for the horizontal surface.

Heating of the wall surfaces and the underlying surface naturally also increases the temperature of the surrounding air. This is confirmed by materials from flight experimental observations made in July and August 1973 and averaged for 3-5 days during periods of clear and semiclear weather. These same tables give data for equivalent and equivalent-effective temperatures computed using the P. A. Kondrat'yev formulas [7].

The southern wall of a four-story building situated in a group of houses heats the adjacent air layers. As a result, at a distance of 1.5 m the air temperature on the average is 1.7°C higher in comparison with the temperature at a distance of 1.5 m from the northern wall of a building standing parallel to it. From the moment of incidence of the rays on the north side (about 1530 hours) the air at the wall begins to heat rapidly and after 1.0-1.5 hour the temperature is evened out. The influence of the southern wall is also clearly traced at a distance of 20 m.

The wind velocity in the gap between the long sides of the buildings in the considered case attains maximum values in the middle of the passageway and minimum values at the south wall. The considerable weakening of wind velocity at the south wall must be attributed to an increase in turbulent exchange.

Asphalted surfaces also favor an increase in air temperature. The air temperature maximum in Lenin Square (the central part of Alma-Ata) was greater by 2.3°C at 1430 hours than in an adjacent public garden and the relative humidity was lower by 14% (Table 2).

The temperature differential between the square and the public garden favors the development of convective exchange and an increase in wind velocity over the square by 70% in comparison with the wind velocity at the Alma-Ata Hydrometeorological Observatory and in comparison with the public garden by a factor of four.

On the basis of similar investigations carried out at Samarkand, Volgograd, Ashkhabad, Tashkent, Baku and abroad, it was established that during anticyclonic weather in parks and wooded areas the air temperature can be reduced by 8°C, wind velocity by 80%, and relative humidity is increased by 10-20% [3, 6, 8, 10, 18]. Trees, especially broadleaf trees, forming a continuous wall, are good absorbers of noise, reliably protect living quarters against dust and improve air exchange in the city [15].

Green plantings improve the microclimate of an urban area, create good conditions for rest in the open air, and safeguard the soil and walls of buildings against excessive heating. The distribution of temperature and air humidity in a city can, to a considerable degree, be regulated by rational distribution of green areas.

Taking into account the high effectiveness of green plantings, Z. N. Chebotareva [11] recommends for the conditions of Central Asia a normalization not of the area free from built-up sectors and pavements, but the mass of green with intensive irrigation. A similar opinion was given by Yu. L. Rauner and M. M. Chernavskaya [9] on the basis of the radiation and heat balances of the city. They note that in order to ensure the maximum possible microclimatic effect, in the southern regions of the USSR about 70-80% of the built-up area should be occupied by plantings. In the middle zone this effect is attained with the greening of 50-60% of the built-up area.

In the opinion of many hygienists, the total area of green plantings in a city should occupy approximately half of the entire area [12]. As a result of different peculiarities of cities -- relief, climate and distribution of industrial enterprises -- the distribution of green plantings in the area must be different.

In southern cities, in semidesert and desert zones of our country, due to the great dryness of the air and inadequate soil moistening, especially during the hot period, a need arises for irrigating the territory for the

Table 2

Distribution of Air Temperature t, Relative Humidity r, Wind Velocity u, Equivalent Temperature (ET) and Equivalent-Effective Temperature (EET) in Section Square-Lawn Area-Public Garden and in Meteorological Area of the Hydrometeorological Observatory

Время, ч 1	t°C	r %	u м/сек 2	ЭТ, °C 3	ЭЭТ, °C 4	Время, ч 1	t°C	r %	u м/сек 2	ЭТ, °C 3	ЭЭТ, °C 4
5 *Площадь*						6 *Сквер*					
13	27,1	31	2,0	30,6	29,1	13	25,5	42	0,6	28,8	28,3
14	28,2	26	2,1	31,5	30,2	14	26,1	37	0,6	29,6	29,1
15	28,7	25	1,9	31,9	30,7	15	26,5	33	0,3	30,1	29,8
7 *Газон*						8 *Метеоплощадка ГМО*					
13	27,1	37	1,3	30,3	29,3	13	25,6	42	1,0	28,9	28,1
14	27,3	33	1,1	30,6	29,8	14	26,6	38	1,4	29,9	28,8
15	27,9	32	1,2	31,1	30,3	15	27,7	37	1,7	30,7	29,5

KEY:

1. Time
2. m/sec
3. Effective temperature
4. Effective-equivalent temperature
5. Square
6. Public garden
7. Lawn area
8. Meteorological area Hydrometeorological Observatory

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purpose of maintaining the green areas and ameliorating overheating conditions in the city. In our opinion, the most promising means for supplying water to cities is fountains.

As is well known, fountains are surfaces of active evaporation, and accordingly, heat absorption. Therefore, experimental investigations were carried out at fountains of all types in the city of Alma-Ata. It was established that the fountains reduce the temperature of the adjacent air layer by 1.0-3.0°C and increase the relative humidity by 10-20%. With respect to microclimate, the most effective means was found to be lawn sprayers and these are also recommended for broader use in making a city green and supplying it with water [4]. In combination with green plantings, fountains (in their different variants) are an extremely effective means for reducing the overheating of the environment in the built-up spaces of a southern city.

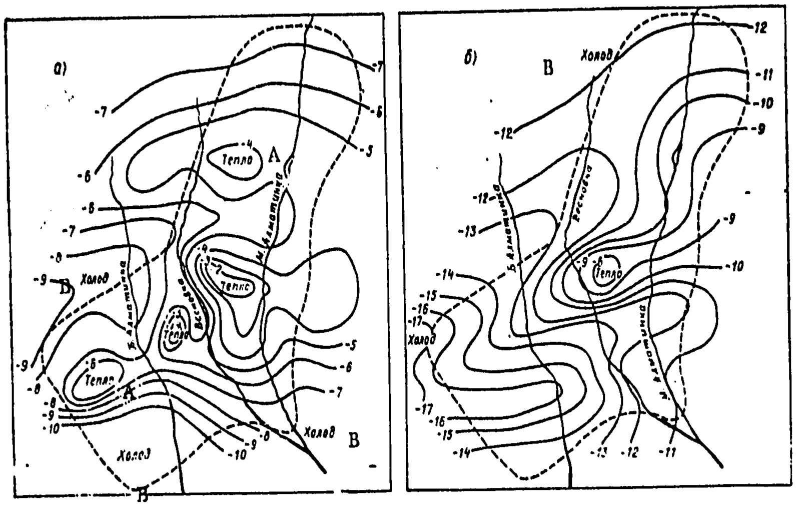

Fig. 1. Field of radiation temperature (°C) of underlying surface at Alma-Ata on the basis of the results of measurements with an airborne radiometer on 12 December at 1550-1800 hours (a) and 13 December 1975 at 0715-0910 hours (b). The dashed line gives the conventional boundary of the city. A) Warm; B) Cold

As mentioned above, on sunny summer days asphalt and concrete pavements are greatly heated and this favors heating of the soil with depth; in addition, an increase in the heating of the underlying surface and the soil in the city is also favored by a considerable increase in wind velocity. And this, in combination with the above-mentioned factors, favors the formation of an increased temperature background in the city.

For example, observations of soil temperature in the cities Novyy Uzen' (1969-1970) and Balkhash (1971-1972) indicated that in the summer months in the upper 50-cm layer there is an increase by 3.0-5.0°C in comparison with sectors outside the city. As is well known, during winter the radiation heating of the underlying surface is considerably weaker as a result of a decrease in the influx of solar radiation and a more intensive thawing of the snow in the city, but in general a substantial increase in the temperature of the underlying surface persists, which is also favored by the internal heat release of an industrial and communal nature.

The circumstances outlined above indicate, first of all, a complex nature of formation of urban microclimate, second, that local circulations caused by temperature contrasts, seem to be a result of a combining of all the factors enumerated above.

The synchronous instrumental measurement of air and soil temperature within a large city requires enormous efforts. Therefore, we attempted to obtain some idea concerning the field of distribution of temperature contrasts in the city by means of measurements of the radiation temperature of the underlying surface.

Figure 1 shows maps of the radiation temperature field (temperature, taking into account heating by direct solar rays) of the winter underlying surface of Alma-Ata city, plotted on the basis of data from sounding with an IL-18 sounding aircraft of the Main Geophysical Observatory imeni A. I. Voyeykov during periods of maximum and minimum daily heating of the city, that is, for the early evening (1600-1800 hours) and morning (0700-0900 hours) periods on 12-13 December 1975.

In the city in the early evening there are three clearly expressed heat foci. These agree well with areas which are built up with buildings with four or more stories with a great density (Fig. 1a). The most intense of these foci is situated at the center of the city, with a maximum increase in the radiation temperature of the underlying surface up to +0.2°C in the neighborhood of the thermoelectric power station. A second focus with a temperature of -4°C occupies the industrial area of the city. In the western part of the city (microregions) there is the weakest heat focus with a temperature of -6°C, whereas beyond the limits of the city there are sectors with a radiation temperature of -10°C. Along the floodplains of the Malaya and Bol'shaya Almatinka within the city area there is a decrease in the radiation temperature of the underlying surface caused by the runoff of cold air from the mountains. This is manifested particularly clearly in the vicinity of the Bol'shaya Almatinka River. In the northwestern and southwestern parts of the city there are sectors with a stagnating air mass and its cooling.

In the morning the nature of the field of radiation temperatures of the underlying surface of the city somewhat changes. It is possible to trace a temperature decrease over the entire area of the city, but its contrasts with a maximum differential to 10°C at the center in comparison with its margins persist (Fig. 1b).

In conclusion, for improving the microclimate of the city it is possible to recommend the following:

1. For Alma-Ata it is desirable to weaken the "heat islands" by means of creating green zones (parks, public gardens, boulevards) of a meridional direction through the entire city; there must be a further increase in the greening of the built-up urban area. Its distribution should correspond rigorously to the conditions for protecting the city against contaminations, noise and other unfavorable agents.

2. Aircraft soundings with the use of radiometers or heat sensors constitute the optimum method for the regionalization of cities with respect to their temperature regime.

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NONSTATIONARY TWO-PARAMETER MODEL OF THE MAIN OCEANIC THERMOCLINE

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[Article by Professor P. S. Lineykin and A. V. Frolov, USSR Hydrometeorological Scientific Research Center, submitted for publication 12 July 1978]

Abstract: The authors propose a precise solution of the nonstationary problem of structure of the main thermocline. This makes it possible to trace the evolution of disturbances in the temperature field caused by the interaction of currents and the distribution of density in the ocean. At the same time it is possible to obtain a more realistic description of the vertical structure of the temperature field in the ocean than is possible when using "single-parameter" models and to give a quantitative description of the velocity and direction of displacements of characteristic points on the temperature profile (inflection point and point of maximum curvature).

[Text] At the present time a great number of studies have been published on the theory of the main oceanic thermocline, based on geostrophic relationships and the equations of turbulent "diffusion" of density, including all the convective terms (see reviews [6, 7, 16, 17]). Despite the fact that a total solution of this problem, with the influence of shores and bottom relief of the ocean taken into account, has not been obtained even for the simplest boundary conditions, it has been possible to explain theoretically a number of peculiarities of the vertical structure of the ocean and the thermohaline circulation associated with it.

The successes attained are associated to a considerable degree with the use of stipulated models of the distribution of the density anomaly δ (relatively constant value at the bottom) along the vertical. For computing the density profile in these models it is necessary to know only one parameter, which is found from solution of the problem; therefore they are called single-parameter models.

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At the same time, in the internal regions of large-scale subtropical circulations, occupying extensive areas of the world ocean, there is a more complex structure of the density field. From the surface to depths of several hundred meters the density is virtually constant and only below this begins to increase sharply (vertical profile δ with an inflection point). Single-parameter models are inconvenient for describing such types of vertical density distribution and this greatly narrows the sphere of their application.

In order to eliminate the mentioned shortcoming of single-parameter models, in [8, 15] a homogeneous layer is "spread" over the thermocline. However, for closing the problem with such an approach it is impossible to get by without additional assumptions, for example, the requirement that vertical velocity at the discontinuity of two layers be equal to zero [8].

The purpose of this study is formulation of a two-parameter model, which will make it possible to describe more complex density distributions than an exponential or any other single-parameter model. In particular, a two-parameter model can represent different δ profiles having an inflection point or some other characteristic points and the deformations of such profiles with time can be traced (reference is to long-period changes with a characteristic time scale of about several months). In addition, it is of theoretical and practical interest to investigate the transport and deformation of a density (temperature) disturbance at the free surface of the ocean, stipulated at some initial moment in time.

The proposed model is simple and the most natural generalization of an exponential δ distribution. At the same time, the fundamental equations of the dynamics of a baroclinic ocean can be here completely satisfactory under some additional conditions which will be mentioned below.

1. Formulation of Problem

We will examine a nonstationary circulation in a baroclinic ocean outside the boundary layers. The ocean is situated on a β-plane, has a finite depth and is bounded only by an eastern shore, which is arbitrarily modeled by a vertical wall extending along a meridian. The dynamics of circulation is governed by the vertical Ekman velocity w_d and the density anomaly δ_d stipulated at the lower boundary of the friction layer. Going on the basis of estimates of the orders of magnitude in the fundamental equations of hydrothermodynamics for a baroclinic ocean [1, 5], we take the initial system of equations in the form

$$2\,\vec{\Omega}\rho\vec{v} = -\nabla p - g\rho\vec{k}; \tag{1.1}$$

$$\nabla(\rho\vec{v}) = 0, \tag{1.2}$$

$$\rho = \rho_0(1 - \alpha^* T); \tag{1.3}$$

$$\frac{\partial T}{\partial t} + \vec{v} \cdot \nabla T = \varkappa \frac{\partial^2 T}{\partial z^2}, \tag{1.4}$$

where $\varkappa$ is the coefficient of vertical turbulent heat diffusion; $\vec{\Omega}$ is the vector of the earth's rotation; $\vec{v}$ is the velocity vector; p is the pressure anomaly P ($p = P - \rho_H g z$); ρ is density; ρ_0 is standard mean density; $\vec{k}$ is a unit vector of the normal to the β-plane; T is temperature; α^* is the coefficient of thermal expansion of water ($\alpha^* = 2 \cdot 10^{-4} (°C)^{-1}$); g is the acceleration of free falling.

The system of Cartesian coordinates is left-handed, the OX-axis is directed to the east, the OY-axis is directed to the north, the OZ-axis is directed downward. The origin of coordinates is situated on the eastern shore in the temperate latitudes. The lower boundary of the Ekman layer at the ocean surface is selected as the origin for reading of the vertical coordinate ($z = 0$).

The approximations made in the derivation of equations (1.1)-(1.4) filter the rapid wave movements in the ocean, but maintain the slow process of mutual adaptation of the density and current fields with a characteristic time scale of about several months.

Using the "potential" function

$$Q(x, y, z, t) = \frac{1}{g} \int_0^z p(x, y, z, t)\,dz + Q_1(x, y, t) \tag{1.5}$$

the system (1.1)-(1.4) can be reduced to a single equation for Q [5]:

$$\dot{Q}'' + \frac{g}{\rho_0 f} J(Q', Q'') + \frac{\beta g}{\rho_0 f} Q_x Q''' = \varkappa Q^{IV}. \tag{1.6}$$

The derivatives of x, y are denoted by indices, of z -- by primes, of t -- by a dot over the variable; J is the Jacobi operator, f is the Coriolis parameter ($f = f_0 + \beta y$), $\beta = df/dy$ is the Rossby parameter.

We will stipulate the vertical boundary conditions:

$$z = 0: \quad w = w_d(x, y, t), \quad \delta = \delta_d(x, y, t); \tag{1.7}$$

$$z = H(x, y): \quad w = u \frac{\partial H}{\partial x} + v \frac{\partial H}{\partial y}, \quad \frac{\partial \delta}{\partial z} = 0. \tag{1.8}$$

Here w_d is vertical velocity at the friction level

$$w_d = -\frac{1}{\rho_0} \operatorname{rot}_z \frac{\vec{E}}{f}; \tag{1.9}$$

$\vec{E}$ is wind shearing stress at the free surface; δ_d is the density anomaly at the friction level. $\vec{E}$ and δ_d are considered to be known from observations.

The first of the expressions (1.8) is the condition for bottom streamline flow $z = H(x,y)$ of a barotropic current; the second expresses absence of a density flow on the bottom of the basin.

On an eastern shore it is natural to require that the normal component of velocity V_n and the normal derivative of the density anomaly $\partial\delta/\partial n$ be equal to zero. However, the selected method for solving the problem does not make it possible to satisfy these boundary conditions and therefore we replace them by less rigorous conditions:

$$\Gamma) \int_0^H V_n \, dz = 0, \quad \int_0^H \delta V_n \, dz = 0. \tag{1.10}$$

Now we will proceed to the dimensionless variables, related to the main variables by the following expressions:

$$x = L\bar{x}, \quad y = L\bar{y}, \quad z = Z_0\bar{z}, \quad t = \Theta_0\bar{t}, \quad \delta = \delta_0\bar{\delta}, \quad f = f_0\bar{f} \tag{1.11}$$

where L is the horizontal scale, Z_0 is the characteristic depth of the thermocline, θ_0 is the time scale, δ_0 is the characteristic δ value.

Using them we transform equation (1.6) to the form

$$\dot{\bar{Q}}'' + \frac{\gamma}{\bar{f}^2} \bar{Q}_x \bar{Q}''' + \frac{\gamma}{\alpha \bar{f}} J(\bar{Q}', \bar{Q}'') - \gamma\vartheta \bar{Q}^{IV} = 0. \tag{1.12}$$

In place of (1.8) we obtain

$$\bar{z} = 0: \quad \bar{Q}_x = \lambda \bar{f}^2 \bar{\tau}(\bar{x}, \bar{y}, \bar{t}), \quad \bar{Q}'' = \bar{\sigma}(\bar{x}, \bar{y}, \bar{t}), \tag{1.13a,b}$$

$$\bar{z} = \bar{h}: \quad \bar{Q}_x = \alpha^{-1} J(\bar{Q}, \bar{h}'), \quad \bar{Q}''' = 0. \tag{1.14a,b}$$

Here the following dimensionless coefficients appear

$$\gamma = \frac{\beta g \delta_0 Z_0 \Theta_0}{\rho_0 f_0^2 L}, \quad \alpha = \frac{\beta L}{f_0}, \quad \vartheta = \frac{\varkappa \rho_0 f_0^2 L}{\beta g \delta_0 Z_0^3}, \quad \lambda = \frac{f_0 E_0}{\beta g \delta_0 Z_0^2} \tag{1.15}$$

and the dimensionless functions

$$\bar{\tau}(\bar{x}, \bar{y}, \bar{t}) = \overline{-\operatorname{rot}_z \frac{\vec{E}}{f}}, \quad \bar{\sigma} = \frac{\delta_H}{\delta_0}, \quad \bar{h} = \frac{H}{Z_0}, \tag{1.16}$$

the physical sense of which is obvious. In particular, λ reflects the wind effect, ϑ is turbulent heat diffusion, $\bar{h}$ is dimensionless ocean depth.

The principal unknowns of the problem are expressed through the potential function in the following way (the lines over the notations of the dimensionless values have been omitted):

$$u = -\frac{g\delta_0 Z_0}{\rho_0 f_0 L}\cdot\frac{Q'_y}{f},\quad v = \frac{g\delta_0 Z_0}{\rho_0 f_0 L}\cdot\frac{Q'_x}{f};$$

$$w = \frac{\beta g\delta_0 Z_0^2}{\rho_0 f_0^2 L}\cdot\frac{Q_x}{f^2},\ p = g\delta_0 Z_0 Q',\quad \delta = \delta_0 Q''; \tag{1.17}$$

$$\zeta = -\frac{\delta_0 Z_0}{\rho_0}\cdot Q'|_{z=0} + \frac{p_a}{\rho_0 g},$$

where u, v, w are the velocity components along x, y, z, ζ is the level of the free surface.

For evaluating the numerical values of the external parameters of the problem we assume

$$f_0 = 10^{-4}\text{sec}^{-1},\ \beta = 1.5\cdot10^{-13}\text{cm}^{-1}\cdot\text{sec}^{-1},\ L = 5\cdot10^{8}\text{cm},$$
$$Z_0 = 10^{5}\text{ cm},\ \delta_0 = 1.5\cdot10^{-3}\text{ g/cm}^3,\ E_0 = 1\text{ g/(cm}\cdot\text{sec}^2),$$
$$\varkappa = 1\text{ cm}^2/\text{sec},\ \theta = 2\cdot10^{7}\text{ sec},\ g = 10^{3}\text{ cm/sec}^2. \tag{1.18}$$

Then we will have

$$\gamma = 0{,}1,\quad \alpha = 0{,}75,\quad \lambda = 4{,}4\cdot10^{-2},\quad \theta = 2{,}2\cdot10^{-2}. \tag{1.19}$$

In [5] it was demonstrated that the representation of Q in the form

$$Q(x, y, z, t) = U(x, y, t) + zN(x, y, t) + M(x, y, z, t) \tag{1.20}$$

makes it possible to study separately the dynamics of the thermocline and the barotropic layer situated beneath it, taking their interaction into account. The barotropic components of current velocity determined by the first two terms are not dependent on depth. However, baroclinic motion attenuates with depth and for all practical purposes is concentrated within the limits of the thermocline. The functions U and N are selected in such a way that M(x, y, h, t) = M'(x, y, h, t) = 0.

Substituting (1.20) into (1.12)-(1.14) and using the boundary condition (1.14a) for excluding U_x, we obtain

$$\dot{M}'' + \frac{\gamma}{f^2}\left[\frac{f^2}{\alpha} J(N, \eta) + zN_x + M_x\right] M''' + \frac{\gamma}{\alpha f} J(N + M', M'') - \gamma\theta M^{IV} = 0, \tag{1.21}$$

$$z = 0:\quad M_x = \lambda f^2\tau - \frac{f^2}{\alpha} J(N, \eta),\quad M' = \tau; \tag{1.22a,b}$$

$$z = h:\quad M = M' = M''' = 0, \tag{1.23}$$

where $\eta = h/f$ is "reduced" ocean depth.

Thus, it is necessary to solve equation (1.21) for the unknown functions M(x, y, z, t) and N(x, y, t), satisfying the five boundary conditions (1.22 a,b), (1.23) vertically ((1.22a) in this case will serve for determining N) and the two "softened" boundary conditions (1.10) on the lateral wall, and also the initial conditions, which will be formulated later.

2. Solution Method

We will use a representation of the baroclinic component of the potential function in the form [7]

$$M(x, y, z, t) = [m(x, y, t) + n(x, y, t) \cdot z]\, e^{-k(x, y, t)z}, \qquad (2.1)$$

where m, n, k are unknown functions, which must be found. Since one of these is expressed using the boundary condition through the other two, there are two independent parameters in (2.1) and the model can be called a two-parameter model.

It is easy to confirm, using expressions (1.17), that with $n = 0$ the function k^{-1} corresponds to the concept "depth of the baroclinic layer of the sea," defined as the level at which the density anomaly is attenuated by a factor of e relative to its value at the surface and m is the stream function of baroclinic total flows, multiplied by the Coriolis parameter f.

In any density models there must be satisfaction of the physical requirements of attenuation of the density anomaly with depth and stability of stratification of waters, which for our two-parameter model have the form

$$\begin{gathered} k>0; \\ \delta = M'' = (mk^2 - 2\,nk + nk^2z)\, e^{-kz} < 0; \\ \frac{\partial \delta}{\partial z} = M''' = (3\,nk^2 - mk^3 - nk^3z)\, e^{-kz} > 0, \end{gathered} \qquad (2.2)$$

and if the regions of the world ocean situated in the subtropical latitudes are considered, also the requirement of the existence of an inflection point on the density profile:

$$\text{when} \quad z_n > 0 \quad M^{IV} = 0, \qquad \text{that is} \quad z_n = \frac{4\,n - mk}{nk} > 0, \qquad (2.3)$$

$$\text{or} \quad M^{IV}(x, y, 0, t) = k^3(mk - 4n) > 0, \qquad (2.3a)$$

where z_n is the depth of the inflection point.

After elementary transformations of the system of inequalities (2.2), (2.3a) we obtain

$$\begin{gathered} k>0; \\ mk<(2-kz)n; \\ mk<(3-kz)n; \\ mk>4n. \end{gathered} \qquad (2.4)$$

Conditions (2.4) impose some restrictions on choice of the functions m, n, k. They must be satisfied, at least, within the limits of the baroclinic layer, since in the abyssal layer the density anomaly δ becomes negligible and the restrictions on m, n, k lose sense.

The difference in the values enclosed in parentheses in the thermocline is positive. Therefore, if $n > 0$, it follows from the first three expressions (2.4) that $mk < (2-kz)n$ and according to the last expression (2.4) the vertical δ profile cannot have inflection points. However, if $n < 0$, then $m < 0$, $mk < (3-kz)n$ and in the region of values $4n < mk < (3-kz)n$ there will be an inflection point on the density profile. Wishing to describe vertical density profiles of both types, we will adopt the latter requirement, which we reinforce (in order to get rid of the variable coordinate z), assuming $z = 0$, that is

$$n<0, \quad m<0, \quad mk<3n. \tag{2.5}$$

Substituting expression (2.1) into (1.21) we obtain the equation

$$(F_1+F_2z+F_3z^2)\,e^{-kz}+(F_4+F_5z+F_6z^2+F_7z^3)\,e^{-2kz}=0, \tag{2.6}$$

which is satisfied identically for any z if all the coefficients F_i ($i = 1, \ldots, 7$) are equal to zero, that is

$$\begin{gathered} F_1=\gamma^{-1}[2\,(mk-n)\,\dot{k}+k^2\dot{m}-2\,k\dot{n}]-\frac{(mk-3\,n)\,k^2}{a}\,J\,(N,\,\eta)- \\ -\vartheta k^3\,(mk-4\,n)+\frac{1}{af}\,[2\,(mk-n)\,J\,(N,\,k)+k^2J\,(N,\,m)- \\ -2\,kJ\,(N,\,n)]=0, \end{gathered} \tag{2.7}$$

$$\begin{gathered} F_2=\gamma^{-1}\,[k^2\dot{n}-(mk-4\,n)\,k\dot{k}]-\frac{k^3n}{a}\,J\,(N,\,\eta)-(mk-3\,n)\times \\ \times\frac{k^2}{f^2}\,N_x-\vartheta\,k^4\,n+\frac{1}{af}\,[k^2J\,(N,\,n)-(mk-4\,n)\,kJ\,(N,\,k)]=0; \end{gathered} \tag{2.8}$$

$$F_3=-\gamma^{-1}k^2\,n\dot{k}-\frac{k^3n}{f^2}\,N_x-\frac{nk^3}{af}\,J\,(N,\,k)=0; \tag{2.9}$$

$$\begin{gathered} F_4=-\frac{k^2\,(mk-3\,n)}{f^2}\,m_x-\frac{1}{af}\,[(mk-2\,n)\,kJ\,(m,\,k)+2\,nJ\,(n,\,k)+ \\ +k^2J\,(n,\,m)]=0; \end{gathered} \tag{2.10}$$

$$\begin{gathered} F_5=-\frac{k^2}{f^2}\,[nkm_x+(mk-3\,n)\,n_x-(mk-3\,n)\,mk_x]- \\ -\frac{1}{af}\,[2\,nk^2J\,(m,\,k)-2\,nkJ\,(n,\,k)]=0; \end{gathered} \tag{2.11}$$

$$F_6=-\frac{nk^3}{f^2}\,[kn_x-(2\,mk-3\,n)\,k_x]-\frac{nk^2}{af}\,J\,(n,\,k)=0; \tag{2.12}$$

$$F_7=\frac{n^2k^3k_x}{f^2}=0. \tag{2.13}$$

It follows from the latter condition that

$$k=k(y,\ t). \tag{2.14}$$

Therefore, (2.12) can be written in the form

$$-\frac{nk^2 n_x}{f}\left(\frac{k_y}{\alpha}+\frac{k}{f}\right)=0. \tag{2.15}$$

If it is assumed that $n_x = 0$, condition (2.11) gives either $m_x = 0$ or $k = \mathrm{const}/\sqrt{f}$. Selecting the second, we arrive at a contradiction, since according to (2.10) the m function is not dependent on

$$x\ \left[m=\left(4n+\frac{2f}{\alpha}n_y\right)\sqrt{f}\right].$$

but according to (2.11) $m_x \neq 0$. The possible case $n_x = m_x = 0$ requires, in accordance with (2.7)-(2.9) also that $N_x = 0$ and represents a physically "degenerate" purely zonal motion in the ocean, for which the horizontal advection of heat is equal to zero. It is not of practical interest and therefore we satisfy the equation (2.15), assuming $k_y/\alpha + k/f = 0$, that is

$$k=C_1(t)/f, \tag{2.16}$$

where $C_1(t)$ is an arbitrary function of time.

Substituting (2.16) into (2.9), we find that C1 is a constant. It is inversely proportional to the Z_0 value, which without restriction of universality can be selected in such a way that $C_1 = 1$ (in the northern hemisphere).

Then

$$k=f^{-1}. \tag{2.17}$$

With (2.17) taken into account, conditions (2.10), (2.11) assume the form

$$(2\alpha n-m_y)\,n_x+\left(\frac{\alpha}{f}n+n_y\right)m_x=0; \tag{2.18}$$

$$(fn-m)\,n_x+nm_x=0. \tag{2.19}$$

The homogeneous equation (2.19) has the solution

$$m(x,\ y,\ t)=n[C_2(y,\ t)-f\ln|n|]. \tag{2.20}$$

Substituting (2.20) into (2.18), we obtain an equation for determining C_2:

$$C_{2y}-\frac{\alpha}{f}C_2-\alpha=0. \tag{2.21}$$

Hence

$$C_2(y,\ t)=f[C_3(t)+\ln f], \tag{2.22}$$

and with (2.20) taken into account

$$m(x, y, t) = fn\left[C_3(t) - \ln\frac{|n|}{f}\right], \tag{2.23}$$

where $C_3(t)$ is an arbitrary function of time.

Taking expressions (2.17), (2.23) into account, we transform equations (2.7), (2.8):

$$\dot{n} + \frac{n\dot{C}_3}{s-3} - \frac{\gamma\vartheta n\,(s-4)}{f^2\,(s-3)} - \frac{\gamma n}{\alpha f}\, J(N, \eta) + \frac{\gamma}{\alpha}\, J\left(N, \frac{n}{f}\right) = 0, \tag{2.24}$$

$$\dot{n} - \frac{\gamma\vartheta n}{f^2} - \frac{\gamma n}{\alpha f}\, J(N, \eta) + \frac{\gamma}{\alpha}\, J\left(N, \frac{n}{f}\right) = 0, \tag{2.25}$$

where $s = C_3(t) - \ln\frac{|n|}{f}$. (2.25a)

These equations will be compatible and, moreover, identical, if

$$\frac{n\dot{C}_3}{s-3} - \frac{\gamma\vartheta n\,(s-4)}{f^2\,(s-3)} + \frac{\gamma\vartheta n}{f^2} = 0, \tag{2.26}$$

hence

$$C_3(t) = -\frac{\gamma\vartheta}{f^2}\, t + A, \tag{2.27}$$

where A is an arbitrary constant.

However, in accordance with (2.23), C_3 cannot be dependent on y and therefore it must be assumed that $\vartheta = 0$ (or it must be assumed that (2.27) is satisfied approximately, since ϑ is a small parameter).

Then in place of (2.24), (2.25) we will have

$$\dot{n} - \frac{\gamma n}{\alpha f}\, J(N, s + \eta) = 0. \tag{2.28}$$

Thus, it is easy to see that if the functions n and N are found from equations (2.28), (1.22a) with the use of softened boundary conditions (1.10), the corresponding initial condition and the expressions (2.17), (2.23), using them it is possible to find a solution for the baroclinic component M. The boundary conditions at the bottom (1.23) are satisfied approximately, since the dimensionless ocean depth is $h \simeq 4$ and with a suitable choice of the constant

$$C_1(C_1 = 1)\, e^{-kh} = e^{-\frac{h}{f}} \simeq 0.$$

It is impossible to determine the constant A within the framework of the problem for an unclosed region, but it can be selected on the basis of field data [13]. With (1.22b) taken into account, the $\vec{E}$ and σ fields, independent of one another in nature, in our model are related by the expressions (2.28), (1.22a), (2.23). Therefore, the condition for σ at the ocean surface (1.22b) cannot be arbitrary, which, however, does not contradict the general formulation of the problem because a special solution is sought for satisfying specially selected boundary conditions. This problem is considered in greater detail in the example of a stationary circulation in the North Atlantic [13].

3. Nonstationary Solution

We will examine some possible temporal changes in the mean state of the main oceanic thermocline. Dispensing with allowance for the influence of the boundary conditions on the ocean shore, we will stipulate only the initial conditions for equation (2.24) in the form

$$t=0: \quad n=n_0(\xi, y),\ x=\xi, \tag{3.1}$$

that is, we will solve the problem seemingly for a boundless ocean. As a simplification, we will assume h = const. Then, integrating (1.22a), we find that

$$N(x, y, t) = -h^{-1}(\lambda f^2 \tau x - m) + R(t), \tag{3.2}$$

where R(t) is an arbitrary function of time.

Substituting expression (3.2) for N(x,y,t) into equation (2.24) and using, for shortening the writing, the new function q(x,y,t) = -n/f, we obtain

$$\dot{q} - \gamma\left[\left(B - \frac{h-2f}{fh}\ln q\right) q q_x + \frac{\lambda\tau}{f} q + \frac{\lambda}{afh} J(f^2 \tau x, q)\right] = 0, \tag{3.3}$$

where

$$B(y) = f^{-1}\left(\frac{h-2f}{h} A - 1\right). \tag{3.4}$$

If we neglect the wind effect (with selected values E_0, δ_0, Z_0 the parameter $\lambda = 4.4 \cdot 10^{-2} \ll 1$), then in place of (3.3) we will have the equation

$$\dot{q} - \gamma\left(B - \frac{h-2f}{fh}\ln q\right) q q_x = 0. \tag{3.5}$$

Its solution with the initial condition

$$t=0: \quad q = q_0(\xi, y) = -\frac{n_0}{f} \tag{3.6}$$

is

$$x = \xi - \gamma\left(B - \frac{h-2f}{fh}\ln q_0\right) q_0 t. \tag{3.7}$$

For facilitating the physical interpretation of the solution (3.7) we introduce the function

$$\Phi(x, y, t) = \left(A - \frac{h}{h-2f} - \ln q\right) q = -\sigma + \left(2 - \frac{h}{h-2f}\right) q, \tag{3.8}$$

whose mean (temporal) values we evaluate applicable to the conditions for an anticyclonic circulation in the North Atlantic. For this purpose we use the numerical values of the functions $q_s(x,y)$, $\sigma_s(x,y)$, satisfying the solution of the stationary problem. In this case it follows from equation (3.5), that $q_s = q_s(y)$ and then, in accordance with (1.22b) $\sigma_s = \sigma_s(y)$. The form of these functions can be determined using the boundary conditions (1.10). The corresponding computations are given in [13]. Their results with $x = 0$, $h = 4$, $\Lambda = 4$ are given in Table 1. We see that over the greater part of the ocean area the absolute values of the functions $\Phi_s(0,y)$ and $\sigma_s(0,y)$ are close to one another and coincide accurately when $y = 0$.

Taking (3.8) into account and multiplying equation (3.5) by $d\Phi/dq$, we obtain

$$\dot{\Phi} - \gamma \frac{h-2f}{fh} \Phi\Phi_x = 0, \tag{3.9}$$

and in place of (3.7)

$$x = \xi - \frac{\gamma}{fh} (h - 2f) \Phi_0 t, \tag{3.10}$$

where $\Phi_0(\xi, y)$ is the value $\Phi(x,y,t)$ when $t = 0$.

Table 1

	y				
	−0,5	−0,3	0	0,3	0,5
q_s	2,36	1,74	1,00	0,51	0,30
σ_s	−2,69	−2,52	−2,00	−1,35	−0,36
Φ_s	4,22	3,32	2,00	0,91	0,36
$\Phi_s+\sigma_s$	1,53	0,80	0	−0,44	−0,30

The processing of great masses of data from in-transit shipboard and expeditionary observations of temperature T_w of the ocean surface shows [for example, 2, 14] that in the region of synoptic spatial scales (cf about 1,000 km) T_w over the course of months, seasons and longer time intervals differs by 1°C or more from the mean long-term values. Detailed large-scale deviations of T_w from the norm are usually called "anomalies." But since we have already used this term in another sense, instead of it we will use the word "disturbance," assuming them to be equivalent.

Mathematically the initial disturbance of the stationary density field at the ocean surface, which, in accordance with (3.8), can be expressed in terms of the function $\Phi(x,y,t)$, will be written in the form

$$\Phi_0(x, y, 0) = \Phi_s(\xi, y) + \varepsilon\varphi(y)\psi(\xi). \tag{3.11}$$

where $\Phi_s(\xi, y)$ is a stationary field, not dependent on x, ε is the amplitude of the disturbance, $\varphi(y)$, $\psi(\xi)$ are functions determining the dimensions and form of the disturbance.

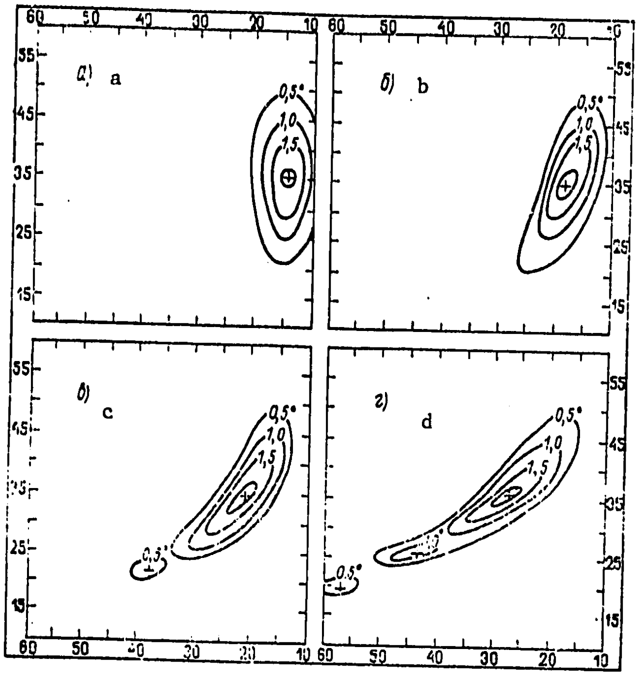

Fig. 1. Computations of evolution of spot of warm water at ocean surface. a) t = 0, b) t = 1/2 year, c = 1.2 year, d) t = 2.4 years

In particular, wishing to reproduce the situation illustrated in Fig. 1-6 in [14], we will stipulate with t = 0 $\varepsilon = 0.2$, $\varphi(y) = e^{-(\varkappa_1 y)^2}$, $\psi(\xi) = e^{-(\varkappa_2 \xi)^2}$, $\varkappa_1 = 4$, $\varkappa_2 = 10$, that is, a spot of warm water at the ocean surface in the form of an ellipse with an extent along the x-axis of about 1,000 km and along the y-axis of about 3,000 km. The amplitude of the disturbance is maximum in the middle latitudes. Using Table 1 and the equation of state (2.3), it is easy to establish that with the selected values of the parameters α^*, δ_0 at the center of the spot the temperature deviation of the water ΔT_w from the norm is about 1.5°C. The initial disturbance in the form of isolines of the function $\Phi_0(x,y,0)$ is shown in Fig. 1a. For greater clarity, the figure shows the values ΔT_w, which, according to the estimates made above, have approximately the same spatial distribution as the function $\Phi_0(x, y, 0)$.

Taking into account that the considered disturbance is weak, that is,

$$\frac{\Phi - \Phi_s}{\Phi_s} \ll 1,$$

from equation (3.9) we obtain an approximate expression for the phase velocity of transport of the disturbance C_f:

$$C_f = -\gamma \frac{h-2f}{hf} (B - \ln q_s)\, q_s. \tag{3.12}$$

Using the q_s values from Table 1, we find, in accordance with (3.12), that in the northern part of the solution region ($y = 0.5$) C_f is of the order of 100 km/year, and in the subtropics ($y = -0.5$) -- 10 times greater (up to 1,500 km/year).

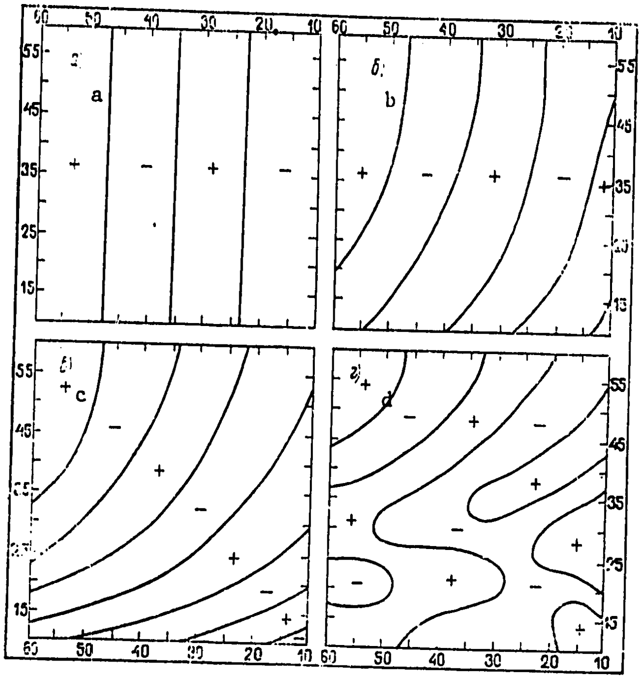

Fig. 2. Computation of evolution of harmonic disturbance. a) $t = 0$, b) $t = 1/2$ year, c) $t = 1.8$ year, d) $t = 5.4$ years. The solid curves separate regions of positive and negative values of disturbance of the function $\Phi(y, x, t)$.

The evolution of the disturbance is shown in Fig. 1b,c,d. It can be seen that the initial spot of warm water is displaced to the west, or more precisely, taking into account the dependence of C_f on latitude, to the west-northwest. This same factor causes a characteristic deformation of the spot (Fig. 1b,c). It is drawn out into a narrow zone with a bend toward the south in the central part. The slight nonlinearity of equation (3.9) leads to the isolines lying closer together in the western part of the disturbance and to the formation of new local centers within it

(Fig. 1d). Qualitatively similar peculiarities of the transport and evolution of the form of this disturbance are shown in Figures 1-6 in [14]. The principal difference is the absence of displacement of the eastern part of the spot to the south according to our computations. However, it can be hoped that allowance for influence of the wind, which creates a meridional circulation, will make it possible to reproduce in the model also this characteristic in the development of a disturbance (with a mean velocity of meridional flow of 1 cm/sec); after a year a fluid particle is 320 km to the south of its initial position.

After the time [11]

$$t_g = -\frac{1}{F'(\xi_g)}, \quad F'(\xi_g) = -\gamma \frac{h-2f}{fh} [\Phi'(\xi_g)]_{\max} \qquad (3.13)$$

there is the first "overturning" of the disturbance, which is manifested mathematically in the multivaluedness of the solution of (3.10). For the initial condition in the form of a spot of warm water at the ocean surface

$$\xi_g = -\frac{1}{\chi_2 \sqrt{2}}, \quad F'(\xi_g) = -\sqrt{2}\gamma\varepsilon\chi_2 \frac{h-2f}{fh} e^{-\frac{1}{2}(\chi_1 y)^2}. \qquad (3.14)$$

Substituting the numerical values of the parameters entering into (3.13), (3.14) for the conditions in the middle latitudes (y = 0), we find that t_g = 7.4 years.

The results of prolonged measurements in experimental polygons indicate that disturbances of the stationary density field with a time scale of months occupy not only the thin surface layer of the ocean, but also the lower-lying water stratum, including the region of the main thermocline. In particular, in the Soviet polygon in the Tropical Atlantic [12] the climatic type of temperature (density) distribution of water T_W (vertically) (without an inflection point) is maintained during the passage of a disturbance, but there is an appreciable change in the depth z_k of the point of the maximum of profile curvature (about 100 m in 80 days). The inconstancy of depth z_k is accompanied by local temperature changes in the main thermocline by 4-6°C, which exceeds the seasonal variability of T_W in this region at the ocean surface (2-3°C). Using the data in our model it is possible to estimate the corresponding change in z_k with time:

at the depth z_k there is approximate satisfaction of the condition $M^V = 0$, hence

$$z_k = f(\ln q + 5 - A). \qquad (3.15)$$

Differentiating (3.15) in time, we find the velocity of vertical movement of the point of maximum curvature

$$\dot{z}_k = f\frac{\dot{q}}{q}, \qquad (3.16)$$

which, with (3.5) taken into account, can be expressed through the values of the functions $q(x, y, t_p)$ and its derivative $q_x(x, y, t_p)$ at a fixed moment in time t_p:

$$\dot{z}_k = \gamma \frac{h-2f}{h} (B - \ln q)\, q_x. \qquad (3.17)$$

The expression h - 2f/h (B - ln q), as can be seen easily, with admissible values of the q function (see Table 1) is always positive and accordingly the sign on $\dot{z}_k$ coincides with the sign on $q_x(x, y, t_p)$.

For an anticyclonic disturbance (the warmer water is situated in the middle) $q_x > 0$ in its western part and $q_x < 0$ in the eastern part. Accordingly, the depth z_k in the western part will increase with time, and in the eastern part will decrease. After passage of the disturbance through a definite point in the ocean the initial density profile is restored in it (without taking energy dissipation into account). If it is assumed that a change in depth z_k occurs at 100 m with an earlier selected time scale θ_0 (constituting approximately 2/3 of the period of the "slow" synoptic waves detected as a result of analysis of time series of the measured current velocity at all points in the polygon [11]), then in accordance with (3.17) and (3.4) with y = 0.3, q = 1.74, A = 4, h = 4 the value $q_x \simeq 1.6$, that is, the disturbance of temperature of the ocean surface with an extent of 500 km along the x-axis should have an amplitude of about 1.3°C.

It is of definite interest to compute evolution of an initial field of the type (3.11) with a periodic function $\psi(\xi)$ ($\varepsilon = 0.2$, $\varphi(y) \equiv 1$, $\psi(\xi) = \sin(4\pi\xi)$). In essence, the adoption of such an initial condition at the parallel is equivalent to stipulation on the meridian of a source of harmonic disturbances similar to that used in [3, 4]. It is therefore not unexpected that the patterns of evolution of the initial field shown here (Fig. 2a,b,c) coincide with the similar patterns in [3, 4]. Additional allowance for the influence of nonlinearity in our model leads to an overturning of the disturbance in the south after 1-2 years and in the north after 8-12 years, which coincides with the estimate of the time t_g of onset of the first overturning of the harmonic wave in the middle latitudes when using a single-parameter model [9] ($t_g \simeq$ 3-4 years). The results of computations for 5.4 years are presented in Fig. 2d. The upper half of the region is occupied by regular waves and the lower half by waves breaking down as a result of the nonlinear effect.

The qualitative similarity in the peculiarities of evolution of the initial density (temperature) disturbance in the ocean to field data, and also the correspondence of the velocity of movement of characteristic points on the vertical density profile to the conditions of the hydrophysical polygon in the northern part of the Atlantic Ocean, indicate the possibilities of the proposed two-parameter model. The principal mechanism considered here is the mutual adaptation of currents and the density field in the ocean. An improvement in the model will make it possible to take into account the influence of bottom relief and the ocean shores and also the wind effect.

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VARIATIONS IN THE WATER VOLUMES IN RIVERS OF THE SOVIET UNION

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 86-91

[Article by Professor K. P. Voskresenskiy, State Hydrological Institute, submitted for publication 31 March 1978]

Abstract: The reasons for long-term variations in water volumes in rivers are deviations from the mean values of the climatic factors of runoff and the influence of economic activity. For most of the rivers in the USSR the runoff norm was established in 1961. Analysis of the results of observations from 1961 through 1976 demonstrated that despite the exceptionally small water volumes of 1971-1976, affecting a great part of the territory of the USSR, the inclusion of these years in the preceding period almost does not change the runoff norm. According to data from a water use inventory in 1976 and computation of the channel water balances of the principal USSR rivers, the magnitude of nonreturnable water consumption is 149 km^3/year, which is approximately 3% of the magnitude of the water resources in USSR rivers. In Central Asia 65% of the water resources are consumed without return, in Transcaucasia -- 20%, in the Northern Caucasus and Kazakhstan -- 18%. Within the limits of the European North, Siberia and the Far East the runoff of rivers is virtually natural.

[Text] The mean magnitude of the water resources of the USSR has been determined repeatedly by different authors.

According to data from B. D. Zaykov and S. Yu. Belinkov (1937), the mean absolute runoff for the territory of the USSR, as indicated by the mean runoff map which they compiled on the basis of data for 1,281 observation

Table 1

Water Inflow into Main Reservoirs on USSR Rivers During the Period 1971-1976

Река 1	Водохранилище 2	3 Многолетняя норма стока, км³	Приток за период 1971—1976 гг. 4	
			км³ 5	в % от многолетней нормы
6 Волга	Рыбинское 14	34,7	23,6	68
Волга	Куйбышевское 15	241	214	89
	Волгоградское 16	254	206	81
7 Кама	Камское 17	52,7	53,7	102
Кама	Воткинское 18	56,1	54,9	98
8 Дон	Цимлянское 19	22,3	13,4	60
9 Днепр	Киевское 20	43,2	32,6	75
Днепр	Каневское 21	43,4	37,2	86
Днепр	Днепродзержинское 22	49,2	42,9	87
Днепр	им. Ленина 23	50,8	42,1	83
Днепр	Каховское 24	50,8	42,8	84
10 Иртыш	Бухтарминское 25	19,4	18,0	93
11 Обь	Новосибирское 26	54,9	52,2	95
12 Ангара	Братское 27	90,8	97,4	107
13 Енисей	Красноярское 28	91,4	87,7	96
По всем водохранилищам 29		1145	1022	89

KEY:

1. River
2. Reservoir
3. Long-term runoff norm, km^3
4. Inflow during period 1971-1976
5. In % of long-term norm
6. Volga
7. Kama
8. Don
9. Dnepr
10. Irtysh
11. Ob'
12. Angara
13. Yenisey
14. Rybinskoye
15. Kuybyshevskoye
16. Volgogradskoye
17. Kamskoye
18. Votkinskoye
19. Tsimlyanskoye
20. Kiyevskoye
21. Kanevskoye
22. Dneprodzerzhinskoye
23. imeni Lenina
24. Kakhovskoye
25. Bukhtarminskoye
26. Novosibirskoye
27. Bratskoye
28. Krasnoyarskoye
29. For all reservoirs

points, is equal to 5-6 liters/(sec·km^2). Proceeding on the basis of this figure, it can be established that the total runoff of USSR rivers is 3,746 km^3/year.

According to a more detailed runoff map, compiled by B. D. Zaykov (1946) on the basis of data for 2,360 observation points, the mean absolute runoff is 5.8 liters/(sec·km^2). The total runoff for the rivers of the USSR is also equal to 3,746 km^3.

Table 2

Change in River Runoff Under Influence of Economic Activity (Using Data from Water Use Inventory)

Экономический район 1	Водные ресурсы, км^3 2	Использование вод 3		Безвозвратные потери 4	
		Забор, км^3 5	Сброс, км^3 6	км^3	В % от водных ресурсов 7
Прибалтийский 8	74,6	6,07	4,43	1,64	2
Белорусский 9	59,0	0,76	0,09	0,67	1
Северо-Западный 10	735,4	13,99	13,34	0,65	≤1
Волго-Вятский 11	160	1,67	1,59	0,08	≤1
Центральный 12	121,6	10,37	9,80	0,57	≤1
Центрально-Черноземный 13	19,8	1,60	0,43	1,17	6
Юго-Западный 14	205	28,24	27,95	0,29	<1
Северо-Кавказский 15	74,4	29,94	16,76	13,18	18
Закавказский 16	79,9	20,72	4,53	16,19	20
Уральский 17	115	3,52	2,89	0,63	1
Поволжье 18	292	15,70	6,08	9,62	3
Казахстан 19	113	28,83	8,02	20,81	18
Средняя Азия 20	126,9	99,60	17,18	82,42	65
Западная Сибирь 21	535	1,30	1,43	−0,13	≤1
Восточная Сибирь 22	1109	3,09	2,78	0,31	≤1
Дальний Восток 23	1820	2,36	2,18	0,18	≤1
Всего 24	4720	268	119	149	3,1

KEY:

1. Economic region	13. Central Chernozem
2. Water resources, km^3	14. Southwestern
3. Water use	15. Northern Caucasus
4. Nonreturn losses	16. Transcaucasian
5. Intake, km^3	17. Ural'skiy
6. Discharge, km^3	18. Volga
7. In % of water resources	19. Kazakhstan
8. Baltic region	20. Central Asia
9. Belorussian	21. Western Siberia
10. Northwestern	22. Eastern Siberia
11. Volga-Vyatskiy	23. Far East
12. Central	24. Total

K. P. Voskresenskiy (1962) determined the total runoff of the rivers of the USSR to be 4,479 km^3/year [4]. This figure was obtained by summing the runoff of the main large rivers of the USSR flowing directly into the sea and the runoff from interfluve areas, determined from the new compiled map. The map was based on data from long-term observations at 5,690 stations.

Detailed calculations of the water resources of the USSR then were cited in a monograph of the State Hydrological Institute entitled VODNYYE RESURSY I VODNYY BALANS TERRITORII SOVETSKOGO SOYUZA (Water Resources and Water Balance of the Territory of the Soviet Union) [2], published in 1967. In this study for the first time we have determined the long-term volumes of the water resources of rivers, administrative oblasts, union republics and large economic regions in the USSR. We determined waters of local runoff forming within the limits of an oblast (rayon, republic), the inflow from adjacent regions and outflow from the considered territory. The total magnitude of the water resources of the USSR was 4,714 km^3.

In 1975, at the State Hydrological Institute, in connection with the preparation of materials for the General Plan for Multisided Use and Conservation of the Water Resources of the USSR, specialists made a more precise determination of water resources [1]. The new computations confirmed the earlier established total volume of the water resources of the USSR. It was found to be equal to 4,720 km^3, or, rounded off, 4,700 km^3. Changes in river runoff were established only in individual regions of inadequately studied regions. These changes are in some cases significant. For example, the water resources of Kamchatskaya Oblast according to former computations were 245 km^3/year, but according to recent calculations -- 303 km^3. For Kamchatka such an increase in water resources is considerable and is about 25%. But the increase in the total water resources of the USSR as a result of this is only about 1%. Investigations made earlier indicated that the total water resources of rivers in the USSR as a whole are quite stable. Their deviations in individual years do not exceed ±10% of the mean volume for a long-term period [5].

The reasons for the long-term variations of river volume can be deviations of the climatic runoff factors from the mean and the influence of economic activity.

In estimating the long-term variations of river runoff it is necessary to ascertain the reliability of the mean volume of water resources or the runoff norm relative to which these variations are determined.

As is well known, the runoff norm is the main characteristic of water resources. For most of the rivers in the USSR it was established in 1961 [4]. The last period of observations from 1961 through 1976 for the main rivers of the USSR was analyzed for the purpose of checking the stability of the runoff norm and its reliability.

At the present time a considerable number of the main large rivers of the USSR have been regulated and reservoirs have been established on them. Therefore, the checking of the change in river volumes during the most recent time period was based on the inflow into reservoirs.

There are now 15 major reservoirs on the principal rivers.

In the analysis of variations in inflow into reservoirs it was found that the 10-year period from 1961 through 1970 was average with respect to volume (the mean modular coefficient was 0.997) and its inclusion in the long-term series does not change the runoff norm. The last six-year period 1971-1976 in the territory of the USSR was characterized by exceptionally small volumes. A particularly low runoff volume was observed in the southern half of the European USSR and in the southern part of Western Siberia. In the Don basin the mean modular runoff coefficient was 0.6, in the Dnepr basin -- 0.75-0.83, in the Volga basin -- 0.68-0.89, in the basin of the upper Irtysh -- 0.93, in the Ob' basin -- 0.95, in the Yenisey basin -- 0.96.

In the northern regions of the European USSR and in Eastern Siberia during this same period the mean runoff was above the norm. In the Kama basin the modular coefficient was 1.02, in the Angara basin -- 1.07. On the average, for all 15 large reservoirs in the territory of the USSR the modular inflow coefficient was 0.89. Such a low-water volume period is exceptional for the territory of the USSR with respect to area affected and the degree of low volume.

Information on inflow into individual large reservoirs during the period 1971-1976 is given in Table 1.

Despite the exceptionally low volume during the period 1971-1976, affecting a large part of the territory of the USSR, the inclusion of these years in the series of preceding observations almost does not change the values of the runoff norms. If one arbitrarily assumes that the onset of observations on USSR rivers was in 1900 (in actuality, they were initiated on the major rivers considerably earlier -- in the 1870's-1880's), the inclusion of the last six low-water years (1971-1976) in the 70-year series (1900-1970) changes the earlier established runoff norms by only 1%.

Thus, it is possible to consider the earlier established runoff norms to be stable and the computed water resources can be considered constant.

The problem of the influence of economic activity on water resources has been studied for a long time.

Water consumption and water use began with the appearance of man, but over a long period of time it did not alter the natural cycling of water.

During the last period of time, approximately since the 1950's, there has been a change in the runoff of individual rivers under the influence of economic activity. These changes were also known earlier, but they were clearly manifested only in regions of intensive development of irrigation -- in Central Asia and the Caucasus, where the waters were used for centuries, and possibly millenia.

It is a widely held opinion that economic activity leads to a decrease in river runoff. However, in some cases as a result of economic measures the river runoff can even increase. This can occur with an improvement in the infiltration capacity of the basin, for example, as a result of deeper plowing of the soil and an increase in the ground water reserves with a simultaneous decrease in total evaporation.

An increase in runoff can be a result of an excess of the discharge of water into rivers over the volume of water intake from them for economic needs.

An analysis of data on the volumes of water intake from and discharge into rivers during 1976 indicated that in some of the most developed regions of the European USSR the volume of water discharged into rivers exceeds the water intake from rivers. The reason for this is that the rivers receive not only "used" industrial, household and irrigation river waters, but also water from ground water horizons and also mine water.

For example, it can be noted that the volume of water discharged into the Neman, Zapadnaya Dvina, Berezina, Oskol, Medveditsa and Kal'mius Rivers exceeds the water intake. For the Oskol River this excess is 0.11 km^3 and for the Kal'mius it is 0.57 km3/year.

A more common situation is an excess of water intake over discharge into the river, and as a result, a decrease in river runoff as a result of economic activity.

An estimate of water use, that is, a direct determination of the influence of economic activity on river runoff in the modern period, can be accomplished on the basis of a determination of the channel water balances of the principal river systems.

The results of computations of channel water balances of the Volga, Kuban', Dnepr, Ural, Amudar'ya and Lena Rivers for 1976, carried out at the State Hydrological Institute, and also data from a water use inventory (intake and discharge) for this same year, generalized for the basins of the main rivers of the USSR and for the territories of economic regions, made it possible to determine the magnitude of nonreturn water consumption and losses in evaporation from the water surface of reservoirs, that is, the decrease in runoff under the influence of economic activity.

As is well known, the intake and discharge of water are determined by technological processes in industry, the area of irrigated lands and the numbers of population.

Water consumption by all three water users does not have marked changes with time and within the limits of several years can be considered constant. Therefore, the magnitude of runoff losses determined in 1976 can be adopted for the near past and future and it is possible to determine the change in water resources under the influence of economic activity during the modern period.

Thus, an estimate was made of the change in total runoff within the limits of individual economic regions and in the territory of the USSR as a whole (Table 2).

The most significant changes in runoff as a result of nonreturn losses occur within the limits of 20% of the territory of the USSR falling in the southern regions of intensive irrigation.

In Central Asia there is a 65% nonreturn removal of the water resources of rivers, in Transcaucasia -- 20%, in the Northern Caucasus and in Kazakhstan -- 18% in each case. Small runoff changes were established in the Central Chernozem region (5%) and in the Volga region (3%). They are still less conspicuous in the Baltic region (2%) and Belorussia (1%). The enumerated regions constitute approximately 10% of the entire territory of the USSR.

Within the limits of an enormous territory, constituting about 70% of the area of our country, occupying the northern part of the European USSR, Western Siberia, Eastern Siberia and the Far East, the nonreturn losses constitute less than 1% of the water resources of rivers. The runoff of rivers in this territory is virtually natural.

The total change in runoff of USSR rivers as a result of nonreturn water consumption is 149 km^3/year, which is equal to approximately 3% of the water resources in the rivers.

If we turn to an analysis of the influence of economic activity on the runoff of individual rivers it can be established that the greatest changes occurred in the river basins on the southern slope. For economic needs there is a nonreturn intake of 62% of the runoff of the Amudar'ya, 60% of the Syrdar'ya runoff, the Terek -- 43%, Kura -- 41%, Ural -- 16%, Kuban' -- 8%; each year there is a 14% removal from the Dnepr, from the Don -- 13%.

It is always of considerable interest to estimate the changes in runoff of the main river of the EuropeanUSSR and the European river with the greatest runoff volume -- the Volga. Proceeding on the basis of an inventory of Volga water use and its channel balance, it can be established that at the present time the runoff of this river has changed by an average of 3%. If we also take into account additional losses in evaporation from the Volga-Kama cascade of reservoirs, constituting about 2 km^3/year, the total runoff losses of the Volga will be about 4%.

It is also necessary to take into account the possible changes in runoff as a result of agricultural and silvicultural melioration in the river basins.

This matter was investigated in detail by V. Ye. Vodogretskiy [3]. According to his data, the greatest changes in runoff as a result of agricultural and silvicultural melioration occurred in the southern regions of the European USSR, but even there they are small. The runoff changes during the period 1935-1975, according to Vodogretskiy, are equal to:

Volga -- 1% of the long-term norm, Dnepr -- 2%, Don -- 3%, Ural -- 2%, Irtysh -- 2%. In the remaining territory of the USSR the influence of agricultural and silvicultural melioration is negligible and need not be taken into account.

The influence of agricultural and silvicultural melioration on the runoff of large rivers is an order of magnitude less than the influence of water use and allowance for it may not significantly change the estimates of the influence exerted on runoff by other economic activity factors.

Thus, by a determination of the use of water and the computation of channel water balances of large rivers it is possible to ascertain the principal losses of river runoff due to economic needs in the modern period.

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UDC 551.578.(46.53+483)

CALCULATIONS OF THE STABILITY OF FRESHLY FALLING SNOW ON A SLOPE

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[Article by Candidate of Physical and Mathematical Sciences V. A. Khalkechev, Moscow Mining Institute, submitted for publication 5 April 1978]

Abstract: On the basis of writing and solution of an equation taking into account the dispersivity of the snow cover and describing the processes of agglomeration of snow particles and their destruction, an attempt is made to estimate the time of occurrence of avalanches at the time of snowfalls or directly after them. Ways to develop a method for computing a forecast of avalanches from freshly fallen snow are defined.

[Text] The investigations which are discussed in this communication were carried out for the purpose of attaining some clarity in the problem of the nature of the stability of a snow cover on a slope during the time of a snowfall or soon after it on the basis of creation of a mathematical scheme for estimating the snow cover.

Here we will attempt to explain some empirical rules and procedures making it possible in actual practice, under specific meteorological conditions, in a given territory, with some degree of success to make a prediction of the onset of the avalanche danger and we note possible ways to improve them.

It is well known that the onset of an avalanche danger period for freshly falling snow is reckoned from the moment when snow of a definite thickness (20 mm of water) has already fallen and the snowfall continues with an intensity not less than a definite value (3 mm/hour). Then, in the presence of a definite thickness of the snow cover, some time interval after cessation of the snowfall is considered dangerous for avalanches.

This indicates that freshly fallen snow can be stable on a slope, despite its sufficiently great thickness, provided that the intensity of the snowfall is small, and vice versa, with great intensities of the snowfall avalanches of snow of a small thickness can be formed. At the same time, the danger of an avalanche is not precluded during a definite time interval after a snowfall, although the intensity of the snowfall (in contradiction to what has been said above) is equal to zero.

This suggests the following proposal: first, that in the case of small (large) snowfall intensities the snowflakes succeed (do not succeed) in becoming agglomerated and this makes the snow cover more (less) stable; second, that in the snow cover processes can transpire which lessen its stability even after a snowfall.

Now we will visualize that the downhill sliding of the snow occurs in the direction of the y-axis (from left to right) and that the mean macroscopic velocity v of its sliding increases in the direction of the z-axis (upwards). In order to simplify the investigation the snow is assumed to be a monodisperse medium. In the snow thickness we discriminate a layer $dz = \delta$ (where δ is the linear dimension of a snowflake) falling between the planes $z = z_0$ and $z = z_0 + \delta$.

If the lower-lying layer in the sliding process moves as a whole with some mean velocity $v = v_0$, the considered layer moves relative to it with a mean velocity $\Delta v = \partial v / \partial z \, dz = \partial v / \partial z \; \delta$.

This movement can be assumed to be governed by a force acting on the considered layer from left to right from the direction of the next layer situated over it and tending to entrain it. This force is determined for the most part by the process of agglomeration of snow particles belonging to the above-mentioned slow layers. It is known from the physics of agglomeration that the contact area of agglomeration between particles increases proportional to time and the time of total agglomeration is determined by the formula [1]

$$t_{\text{agglom}} = \text{const} \exp \frac{w}{kT}, \tag{1}$$

where w is the energy of crystal lattice disintegration, k is the Boltzmann constant, T is absolute temperature.

Evidently, the magnitude of the force f(t) necessary for separating the n-th particle by shear can be considered as conforming to this same law.

Thus, the lesser (greater) is the velocity gradient $\partial v / \partial z$, the greater (lesser) on the average is the time

$$t = \frac{2\delta}{\Delta v} = 2 / \frac{\partial v}{\partial z} \tag{2}$$

that the particles are in contact, the greater (lesser) is the agglomeration area and the greater (lesser) is f(t) and the more stably (less stably) does the snow lie on the slope if the velocity gradient is such that the time t falls in the interval $(0, t_{\text{agglom}})$. With $t > t_{\text{agglom}}$ (small velocity gradients) f(t) = const and, accordingly, the stability of the snow on the slope is not dependent on the velocity gradient in this range of its values. The latter, as is easy to note, can occur for small snow thicknesses or for sufficiently gentle slopes.

Obviously, the shear strength of snow can be expressed by the formula

$$\tau_{\text{snow}} = f(t) \cdot N_1, \qquad (3)$$

where N_1 is the number of snow particle agglomeration contacts for a unit area of the surface of the considered layer with particles of the above-lying layer.

Thus, the shear strength of snow is dependent on the number of snow particle agglomeration contacts and its value changes not only due to an increase in the contact area with time, but also due to a change in the number of contacts of agglomerating particles between the layers in the process of downward sliding of the snow. It is evident that the number of contacts is dependent not only on the number of particles per unit area of the surface of the considered layer, but also on the type of packing. Evidently, it can be assumed that with an increase in the velocity gradient in the snow thickness the probability of existence, even over a short time interval, of packings with a great number of contacts is decreased.

First we will assume that on a slope we have a snow cover of a definite thickness in which there are already active processes of agglomeration of some particles and sticking with the destruction of the contacts of others.

If the number of possible contacts per unit of surface area between two arbitrarily selected layers is denoted N, then the process of agglomeration and destruction can be described by the equation

$$\frac{dN_1}{dt} = k_1 \rho g h_0 \cos\alpha (N - N_1) - k_2 \rho g h_0 \sin\alpha \, N_1 \qquad (4)$$

or, introducing the dimensionless values using the formulas

$$\bar{t} = k_1 \rho g h \cos\alpha \cdot t, \qquad N_1 = N\bar{N}_1, \qquad (5)$$

the latter is rewritten in form (the lines over the letters are omitted)

$$\frac{dN_1}{dt} + \left(1 + \frac{k_2}{k_1} \operatorname{tg}\alpha\right) N_1 = 1, \qquad (6)$$

where k_1 and k_2 are constant coefficients dependent on the velocity gradient, type of snow and totality of meteorological elements; h_0 is the thickness of the snow lying on the slope; ρ is snow density; g is the acceleration of free falling; α is angle of slope.

We will examine two possible extreme cases:

1) At the initial moment there is not even one agglomerating contact ($N_1 = 0$); 2) At the initial moment all the possible contacts are agglomerating ($N_1 = 1$).

In the first case solution of equation (6) has the form

$$N_1 = \frac{1}{1 + \frac{k_2}{k_1} \operatorname{tg} \alpha} \left[1 - \exp\left(- 1 - \frac{k_2}{k_1} \operatorname{tg} \alpha \right) \bar{t} \right], \qquad (7)$$

in the second

$$N_1 = \frac{1}{1 + \frac{k_2}{k_1} \operatorname{tg} \alpha} \left[1 + \frac{k_2}{k_1} \operatorname{tg} \alpha \exp\left(- 1 - \frac{k_2}{k_1} \operatorname{tg} \alpha \right) t \right]. \qquad (8)$$

It is easy to note that equation (6) has an asymptotically stable stationary solution

$$N_{1\ \text{agglom}} = \frac{1}{1 + \frac{k_2}{k_1} \operatorname{tg} \alpha}, \qquad (9)$$

to which the two solutions presented above tend with time (one downward, another upward).

Thus, the snow lying on a slope, depending on its initial state, can with time decrease or increase its shear stress to a definite limiting value, expressed by equation (9). In other words, the avalanche danger after a snowfall is dependent not only on the thickness of the snow cover, but also on the pattern of change in the totality of meteorological elements accompanying a snowfall, which also determines the initial state of the snow cover necessary for finding a special solution of equation (6).

Now we will assume that snow has fallen on a bare slope with a constant intensity. As a simplification of the investigation the dependence of the agglomeration process on the normal gravity component will be assumed to be the same as the dependence of the destruction process on its tangential component, that is, proportional to the intensity of the force. Then the equation describing the agglomeration and destruction processes, for a qualitative investigation can be written in the form

$$\frac{dN_1}{dt} = k_1 \rho g \cos \alpha \, (N - N_1) \, it - k_2 \rho g \sin \alpha \, N_1 \, it \qquad (10)$$

and if we introduce dimensionless values using the formulas

$$\bar{t} = \frac{1}{2} k_1 \rho g \cos \alpha \, it^2, \quad N_1 = N \bar{N}_1, \qquad (11)$$

equation (10) assumes the form of equation (6). It therefore follows that the stationary solution of equation (10) and equation (4) coincide, but the law of tendency to this solution changed greatly: the index of the exponential function became dependent on the square of time.

It is evident that the landslide danger occurs when the tangential component of gravity, acting on the snow,

$$\tau = \rho g \sin \alpha \cdot It \qquad (12)$$

becomes at least for one layer equal to the shear stress, determined by formula (3) and solution of equation (6).

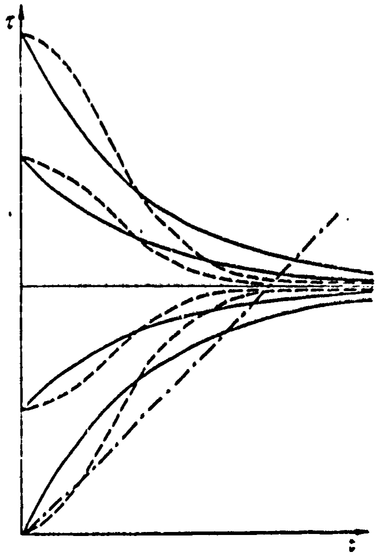

Fig. 1. Approximate pattern of integral curves of equations (6) (solid curves) and (10)(dashed curves). The dashed straight line shows the increase in the tangential component of velocity acting on the snow with a constant intensity of snowfall: t is time, τ is the shear strength of snow and the tangential component of gravity.

It is easy to note that for equation (6) the isoclinic lines are straight lines parallel to the t axis. A sample picture of the directions determined by this equation is shown in Fig. 1. The thick lines represent the shear strength of snow corresponding to a stationary solution of equation (6) and several other regularities of change in snow shear strength corresponding to special solutions obtained for different initial conditions. The dashed line shows similar curves corresponding to equation (10) and the direct growth of the tangential component of gravity with time for the case of a constant intensity of the snowfall. The abscissas of the points of intersection of the dashed straight line and the resistance curves show the time of onset of avalanche danger, that is, the moment when an accelerated movement of the snow can begin. Figure 1 shows that this time is different and is dependent on the initial state of the snow, that is, on the totality of the meteorological elements accompanying a snowfall.

In order to simplify the analysis we examined idealized cases. But in nature during a snowfall there can be a great variation in temperature, intensity of the snowfall and the structure of the falling snow. Accordingly, k_1 and k_2 cannot be constant.

Therefore, a more generalized equation, describing the processes of agglomeration and destruction in the freshly fallen snow cover on a slope, can be written in the form

$$\frac{1}{\rho g \cos\alpha\, k_1(t)\, l(t) \cdot t} \frac{dN_1}{dt} + \left[1 + \frac{k_2(t)}{k_1(t)} \operatorname{tg}\alpha\right] N_1 = N. \tag{13}$$

This equation, as we see, remains linear, and its solution for the initial condition

$N_1 = N_{10}$ when $t = 0$

is written in the form

$$N_1 = \exp(-F)\left[N_{10} + \rho g \cos\alpha \cdot N \int_0^t k_1(t)\, l(t)\, t \cdot \exp(F)\, dt\right], \tag{14}$$

where

$$F = \rho g \cos\alpha \int_0^t k_2(t)\, l(t) \cdot t\, dt; \tag{15}$$

k_1(t) and k_2(t) are functions describing the capacity for snowflakes, depending on weather conditions, to be agglomerated or destroyed in the process of snow moving downslope.

On the curve

[c = snow]

$$N_{1c} = \frac{N}{1 + \frac{k_2(t)}{k_1(t)} \operatorname{tg}\alpha} \tag{16}$$

the right-hand side of equation (13) becomes equal to zero.

It is easy to note that if the ratio k2(t)/k_1(t) is a constant value, we have a stationary solution and the field of integral curves of equation (13) is similar to the corresponding field of equation (6). If for any $t > 0$ $k_2(t) > k_1(t)$, the stability of the snow on the slope decreases, although for some conditions at the initial moment it can also increase. However, if $k_2(t) < k_1(t)$ for any $t > 0$, the stability of the snow increases, although under definite conditions at the initial moment in a short time interval it can also decrease.

Thus, we come to the conclusion that by studying the functions k_1(t) and k_2(t), determined by the totality of meteorological elements and their change with time, it is possible to compute the stability of the snow on the slope and ascertain the avalanche-dangerous period and the moment for the optimum modification of the snow cover for the purpose of preventing a harmful effect from avalanches.

A study of the functions $k_1(t)$ and $k_2(t)$, in our opinion, makes sense. For this it is necessary to carry out purposeful experimental investigations in the laboratory and under field conditions. We assume that this can serve as a basis for creating a method for computing the stability of freshly fallen snow on a slope which is suitable for use in the avalanche service.

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CALCULATIONS OF ACCUMULATION OF MELT WATER BY THE SOIL

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[Article by Candidate of Physical and Mathematical Sciences E. G. Palagin, Leningrad Hydrometeorological Institute, submitted for publication 5 April 1978]

Abstract: In this paper, within the framework of a unified mathematical model, the author examines the processes of snow melting and thawing of the soil. In the model it is proposed that standard observations be used. In practical respects the results can find application in agrohydrology, because the final objective of the computations is a clarification of the conditions for the appearance of a worn ice crust and determination of the moisture reserves in the soil after ending of snow melting. These same results also have application to computations of the dynamics of spring high waters with respect to the detection of runoff losses in infiltration into the soil. An example of the computations is given.

[Text] Intensive thaws or spring snow melting are accompanied by thawing of the soil and the infiltration of moisture. The quantity of percolating water is dependent on meteorological conditions on the eve of the thawing and during its course, the degree of ice saturation of the soil and its temperature. These factors determine the reserve of productive moisture by the time of ending of the spring season and also to a considerable degree the volume of surface runoff during the period of disappearance of the snow cover. The practical importance of the mentioned agrohydrological characteristics explains the great attention which has been devoted to a study of these processes by hydrometeorologists.

The problems relating to snow melting have been examined in detail in [8, 15]. In these sources the emphasis is on the problem of deriving convenient and simple computation formulas on the basis of a series of simplifying assumptions with respect to turbulent flows. This leads to a limiting schematization of the transpiring processes, as a result of which there can be considerable errors in the computations. In addition, within the framework of these methods there are no possibilities of tracing the dynamics of melting and taking into account the influence of the soil. As a result of this type of approaches there is no possibility of tracing the restructuring for the temperature fields in the snow and soil, and also the migration of moisture; this, in turn, does not make it possible to proceed to computation of soil thawing.

There has now been considerable development of the theory of structure of the surface layer of the atmosphere. In addition, the use of the electronic computer is eliminating the problem of numerical calculations when using more complete, and accordingly, more complex models. This is now making it possible to formulate the problem of snow melting on a broadened physical basis with the use of modern concepts concerning the structure of the surface layer, including the soil in the model, and making use of all available meteorological information.

First we will examine the problems relating to snow melting. The quantity of heat I expended on melting from a unit surface in a unit time [15] is

$$I = R + B - P - LE. \qquad (1)$$

where R is the radiation balance; P, E are the turbulent fluxes of heat and vapor; B is the heat flux into the snow; L is the latent heat of vapor formation.

Taking into account the known expressions [3] for P and E, it can be written that

$$E = -\frac{P}{c_p}\frac{q_{ф} - q_{б}}{T_{б} - T_{ф}},$$

[б = b = booth; Ф = v = vane] where q, T, c_p are specific humidity, temperature and heat capacity of the air (the subscripts "0," "b," "v" here and in the text which follow relate to the underlying surface, height of the booth and vane respectively).

Since during melting $T_0 = 0°C$ and $q_0(T_0) = 3.81 \cdot 10^{-3}$ g/g and, in addition, as a result of the entry of melt water into the snow B = 0, in place of (1) it is possible to write the expression

$$I = R - P\left(1 - \frac{L}{c_p} \cdot \frac{3.81 \cdot 10^{-3} - q_{б}}{T_{б}}\right). \qquad (2)$$

[б = booth] Here R can be either computed or taken from observational data, but determination of P is a specific problem, in whose solution we will use a model of structure of the surface layer of the atmosphere (Monin-Obukhov model [11]). For the case of a stable stratification, as is observed in most cases during melting, the specific expressions for the wind u and T are taken from [16]. Then

$$S - S_0 = \frac{S_*}{\varkappa}\left[\alpha \ln \frac{\eta - l}{\eta_0} + 4{,}7\,\frac{\eta - \eta_0 - l}{L_1}\right], \tag{3}$$

where η is the vertical coordinate, directed upward; $\eta = 0$ at the soil surface; η_0 is the roughness parameter; $l(t)$ is the thickness of the snow cover; t is time; L_1 is the Monin-Obukhov length scale.

If $S = u$, then $S_* = v_*$, $\alpha = 1$ (v_* is dynamic velocity). If $S = T$, then $S_* = -P/\rho\, c_p \varkappa v_*$, $\alpha = 0.74$ (ρ is air density).

Using temperature measurements at the level of the meteorological booth $\eta = H_b$ and wind at the vane $\eta = H_v$, we can, taking into account that

$$u\,|_{\eta = l + \eta_0} = T\,|_{\eta = l + \eta_0} = 0,$$

in place of (3) obtain the system

$$\left.\begin{aligned} X &= \ln[(5 - \Pi)/\Pi_0] + 4{,}7\,(5 - \Pi)\,X^3 Y \\ Z X^{-1} Y^{-1} &= 0{,}74\,\ln[(1 - \Pi)/\Pi_0] + 4{,}7\,(1 - \Pi)\,X^3 Y \end{aligned}\right\}, \tag{4}$$

where

$$X = \frac{\varkappa u_\Phi}{v_*};\quad Y = -\frac{g H_б P}{\rho c_p \varkappa^2 \Theta u_\Phi^3};\quad Z = \frac{g H_б T_б}{\Theta u_\Phi^2};\quad \Pi = \frac{l}{H_б};\quad \Pi_0 = \frac{\eta_0}{H_б};$$

[б = booth; Ф = vane] g is the acceleration of free falling; $\Theta \approx 273$°K.

The solution of system (4) makes it possible to find P and from (2) -- I.

Specifically, the computation procedure is reduced to the following. The moment of onset of snow melting can in principle be determined if I at any time during the day becomes greater than zero. However, for this it is necessary to have information on the diurnal variation of meteorological elements and begin checking with a great advance time, and this complicates the computations. Therefore, it is possible and desirable, as an additional indication, to use the date when the maximum daily temperature $T_{b\,max}$ becomes positive. But even then it is possible to miss situations when there is a purely solar melting. It therefore follows that it is necessary to be oriented on the climatic date of onset of melting. However, if up to this moment there is a case with $T_{b\,max} > 0$, it can be used as the basis and checking for $I > 0$ begins with the corresponding date. This same index can and must be taken into account for detecting the moment of onset and ending of a winter thaw. After establishing the initial date, using data from regularly scheduled observations, by the method set forth in [10], we reconstruct the diurnal temperature variation $T_b(t)$. Then each day with an interval of 1 hour we make computations of I. The values u_v^j, q_b^j (j is the time index) are found by means of linear interpolation between successive observation times, and R^j -- similar to T_b^j. Then we determine the snow layer thawing in each interval in the (j+1)-th interval. During periods when $T_b(t)$ remained less than 0 we solved the thermal problem for the entire atmosphere-snow-soil system [18].

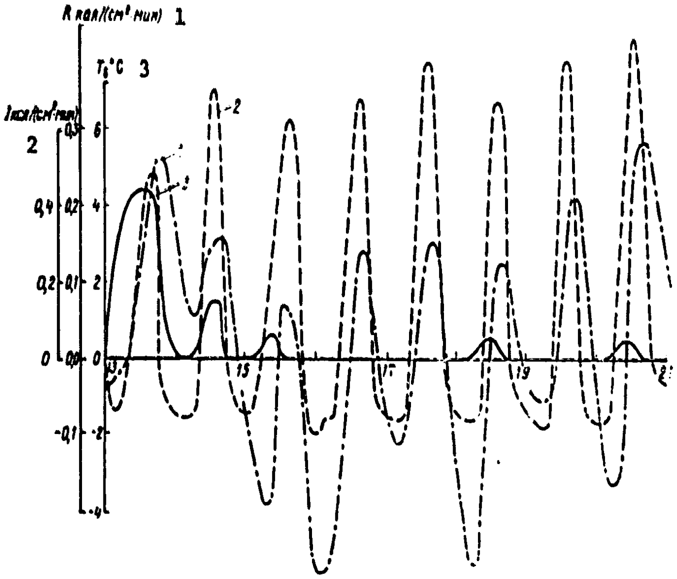

Fig. 1. Temporal variation of air temperature (1), radiation balance (2) and computed values of intensity of snow melting (3). 13-21 March 1972.

KEY:

1. R cal/(cm^2·min)
2. I cal/(cm^2·min)
3. T_b

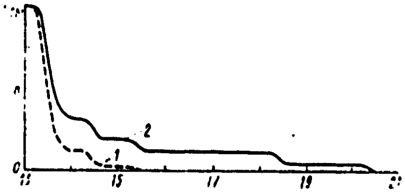

Fig. 2. Comparison of computed (1) and measured (2) depth of snow cover. 13-21 March 1972.

Below we give an example of computations, the material for which was the observational data from the field experimental base of the Main Geophysical Observatory imeni A. I. Voyeykov in the Koltusha region.

Figure 1 gives data on the radiation balance R(t), temperature at the booth level $T_b(t)$ and the computed values of the intensity of snow thawing I(t). Figure 2 gives a comparison of the computed l_{comp} and actual l_{act} snow thickness. The computations show the suitability of the proposed model for practical use because the accuracy of the results for all intents and purposes falls within the range of measurement accuracy. The more rapid disappearance of the snow (in comparison with that actually observed) can be attributed to the absence of allowances for precipitation during the snow melting period; this can in principle be done without significant complications. (In the given case we did not have the appropriate data.)

The snow layer thawing in a unit time in mm of a water column is

$$h_в = \frac{10}{L_п} I, \tag{5}$$

[B = water; π = fusion] where L_{fus} is the heat of fusion.

The water entering into the snow and freezing increases its temperature to 0°C and increases the moisture content to values corresponding to its water-holding capacity. As a result, for some time two zones are observed in the snow thickness: upper, with a temperature of 0°C, bounded by the planes $z = -l(t)$ and $z = -\tilde{l}(t)$ ($\tilde{l}(t)$ is the position of the lower zero isotherm) and lower, which the water has still not reached. With intensive thawing the boundary $\tilde{l}(t)$ moves at a rate equal to the rate of water filtration in the snow. When $\tilde{l}(t)$ becomes equal to zero, the water begins to filter into the soil and thawing of the latter begins. By this time the snow temperature in the entire thickness becomes equal to zero, it passes through the recrystallization stage and its density ρ_{snow} increases approximately to 0.4 g/cm^3, corresponding to the water-holding capacity of 15% of the mass of the solid phase [1]. Henceforth the water release from the snow is determined by a sum consisting of the liquid and solid moisture present in the thawing layer.

The released heat I is expended on freezing at the boundary $\eta = \tilde{l}(t)$ of the water melting from above and is conveyed by thermal conductivity into the lower-lying region. It consists of snow with $T < 0°C$ $(-l(t) \leqslant z \leqslant 0)$, frozen $0 \leqslant z \leqslant h(t)$ and melted $h(t) \leqslant z < H$ soil, where H is the level below which seasonal temperature variations are not reflected. At the upper boundary there should be satisfaction of a balance condition in the form

$$\lambda_c(t) \frac{\partial T}{\partial z}\Big|_{z=-\tilde{l}(t)+0} = I, \tag{6}$$

where λ_{snow} is the snow thermal conductivity coefficient; $z = -\eta$.

In the region $-\tilde{l}(t) \leqslant z < H$ with the moving boundaries $z = -\tilde{l}(t)$ and $z = h(t)$ the thermal conductivity equation is correct and a solution of this problem is possible by the method presented in [13]. We will not here discuss the details, but we will give the sequence of operations involved in the procedure of computing snow melting and the position of the boundary $z = -l(t)$.

Initially we determined the heat expenditures on snow melting I. Then the velocity of movement $\ell(t)$, that is, $v_0 = d\tilde{\ell}/dt$ was assumed to be equal to the rate of filtration of water in the snow $v_{act} = 0.05$ cm/sec [8]. The method proposed in [13] was used in solving the thermal problem in the layer $-\tilde{\ell}(t) \leqslant z < H$, after which we computed the left-hand side of equation (6) and the result was compared with the I value. If $A \leqslant I$, the conclusion can therefore be drawn that the quantity of melting moisture is sufficiently great and the water moves downward with the filtration rate. Otherwise the zero isotherm penetrates into the snow more slowly. Then its rate can be found assuming that $A = L[\rho_{fus} - \rho_{snow}(\tilde{\ell})]v_0$, where $\rho_{sat} = 0.4$ g/cm^3 is the density of the water-saturated snow and $\rho_{snow}(\tilde{\ell})$ are the density values at the boundary prior to the entry of the moisture. In this case it is necessary to have recourse to iterations, successively equating the values on the left- and right-hand sides of equation (6).

As soon as $\tilde{\ell}(t)$ becomes equal to zero, the moisture reaches the soil surface. Then, in the presence of free porosity infiltration begins. These processes were studied under both field conditions and by means of laboratory experiments [2, 4-6, 14]. The theory of this problem is also the subject of a number of studies [9, 12, 17] whose authors propose computation methods based on use of the equation of moisture movement. However, in this case the authors strive to replace the physical relationships by a set of coefficients. Thereby the physical sense of the latter is obscured and, in addition, special experiments are required for their determination. The values obtained are tied in to the specifically used computation model.

The conclusion can be drawn that the use of any "ready-made" computation model for the problem considered here is not possible as a result of differences in purposes and formulation. In this case we are not interested in the field of velocities of the fluid moving in the soil, but the conditions for accumulation and the quantity of moisture accumulated in it. Therefore, it is desirable that the analysis be carried out on the basis of thermophysical principles. This requires allowance for interaction between the atmosphere and the thawing underlying surface by means of a joint solution of a closed system of transfer equations in all the media participating in the process, which in the mentioned investigations was not done.

Now we will turn to an analysis of the processes transpiring in the soil. Here the upper frozen zone $0 \leqslant z < h(t)$ ($h(t)$ is the position of the lower zero isotherm in the soil, and $h(t)$ is the upper zero isotherm position); the $h(t)$ plane is divided into two parts; in the limits $0 \leqslant z < \tilde{h}(t)$ the temperature is equal to 0°C and when $\tilde{h}(t) \leqslant z \leqslant h(t)$ its negative values are observed. Different infiltration regimes can arise in dependence on the intensity of snow thawing and the temperature of the freezing soil: total absorption or appearance of a layer of "supported" moisture. The latter can be caused either by the total plugging of the soil pores by ice or due to an excess of the quantity of melt water above the absorptivity of the soil. Below we will examine the conditions for the appearance of each of the enumerated situations.

As a result of entry of water and its freezing the layer $0 \leqslant z \leqslant \tilde{h}(t)$ is heated to a temperature close to 0°C, but not exceeding it. At the boundary $z = h(t)$ the balance condition must be satisfied

$$\dot{\rho}_в L_п Q = -\lambda \frac{\partial T}{\partial z}\Big|_{z=\tilde{h}(t)+0}; \quad \rho_в L_п Q = \Pi, \tag{7}$$

[B = water; п = fus]

where $\rho_{water}Q$ is the quantity of water entering in a unit time.

Heat transfer upward in this case does not occur due to the absence of a temperature gradient. Thus, heat transfer is directed downward and it is expended on an increase in the soil temperature, which is accompanied by a thawing of that part of the moisture which is transformed into ice when $T < 0$°C. In the solution it is now necessary to examine the two-layer region between the planes $z = h(t)$ and $z = H$ with the discontinuity $z = h(t)$. With $z = h(t)$ the temperature is equal to zero and there is satisfaction of condition (7). In general we apply the algorithm set forth in [13] to this problem.

Now we will examine the problem of the appearance of different thawing regimes. First we will assume that all the melt water, whose quantity we know, reaches $\tilde{h}(t)$. This makes it possible to find the rate in the computation interval from (7) by the trial and error method. For this we first use the rate obtained in the preceding interval and we will solve the problem, by the method developed in [13], for the region $z > \tilde{h}(t)$. As a result, we determine the right-hand side of (7) (the left-hand side in this case must be assumed equal to $L_{fus} Q \Delta t$) and depending on the sign of the discrepancy with the left-hand side we increase or decrease the rate v_{act}. After this the computation cycle is repeated and renewed until it is possible to achieve a coincidence of both terms within the limits of a stipulated degree of accuracy. Thus, we determine the surmised rate of movement of the upper boundary v^j_{act} and its position h^j at the j-th moment in time:

$$\tilde{h}^j = \tilde{h}^{j-1} + v^j_ф \Delta t$$

[Ф = act] (in the first interval $h^0 = 0$ and h^1 is found similarly). Now it is necessary to check whether the determined h^j value really exists. For this we find the volume $\tilde{\Pi}$ which the water entering during the time Δt should occupy:

$$\tilde{\Pi} = \int_{h^{j-1}}^{h^j} \Pi_{св}\, dz,$$

[CB = free porosity] where Π_{free} is free porosity in the frozen zone, equal to

$$\Pi_{св} = \Pi - (w_н/\rho_в + w_л/\rho_л)\, \gamma,$$

[CB = free porosity; H = sat; B = water; л = ice]; Π is soil porosity.

If $\tilde{\Pi} \geqslant \rho_{water} Q \Delta t / \rho_{ice}$, all the water is held and in actuality the earlier determined rate v^{J}_{act} is the rate of movement of the thawing front. (Here it must be remembered that the process of freezing of a water film, that is, the crystallization process, occurs virtually instantaneously as a result of the small radius of the capillaries). In this case all the heat of snow melting is expended on the heating of the frozen soil. However, if $\tilde{\Pi} \leqslant \Delta t \rho_{water} Q / \rho_{ice}$, this means that for heating of the soil it is necessary that there be more ice in the pores than $\tilde{\Pi}$ (under the condition, also, as before, all the heat I is used). Then a blocking layer should arise. And as follows from the preceding reasonings, it will occur if

$$\rho_{ice} L_{fus} \tilde{\Pi} < I \Delta t.$$

Thus, we see that with an increase in the volume of the entering moisture or a decrease in the water transmitting capacity of the soil (in connection with an increase of the ice in it) or as a result of these two factors there can be formation of a layer of supported water. In this case a blocking layer can be formed in the highly cooled soil if at any level the ice saturation becomes close to the total moisture capacity.

The case of "head" filtration in principle cannot be detected because we assume that all the heat I has been expended, this corresponding to the entire quantity of melt moisture Q. And only for illustrative purposes will we point out the possibility of appearance of water resistance. Strictly speaking, a decrease in water permeability of the soil is the basic reason for the appearance of blocked moisture, because thawed or slightly frozen soil has a filtration rate considerably exceeding the thawing rate. Thus, in most cases it is possible to identify the presence of blocked moisture with the presence of a great quantity of frozen water. The latter, naturally, is dependent both on the initial moisture content and on the degree of supercooling of the soil.

We note that the appearance of a blocking layer and the presence of blocked moisture during the period of a thaw are necessary conditions for the appearance of a "worn" ice crust. We feel that the computation methods presented above in principle make it possible to establish the fact of the appearance of an ice crust and also to determine the area of its occurrence.

However, during the period of the spring snow thawing the principal goal is a determination of the quantity of water accumulated by the soil, which is one of the most important agrohydrological characteristics. In the presence of a blocking layer it is equal to the volume of the pores in the above-lying region. But in its absence the moisture reserve is equal to the sum which enters: the moisture content in the soil before the onset of thawing, the quantity of moisture in the snow and precipitation during the period of disappearance of the snow cover. The latter case is realized with a low intensity of snow melting when the soil can be heated or when its temperature by the onset of snow melting is sufficiently high. This corresponds to a small depth of freezing.

An example of the computations is given in Fig. 3. The computations were made using data from the meteorological station Mozhaysk in Moskovskaya Oblast beginning on 2 April 1972 for each day with a one-hour interval. The initial snow thickness was $l^0 = 8$ cm and the freezing depth was $h^0 = 108$ cm. The snow completely disappeared on 8 April, whereas according to computations it should have disappeared on 6 April. The discrepancy can be attributed to nonallowance for the precipitation which fell during this time. In principle it is easy to take this circumstance into account, but in our case this could not be done due to the lack of the appropriate data. During the course of snow thawing no water resistance was observed in the soil and all the forming moisture, in a quantity of 24 mm/cm^2 in the water column entered into the soil. Figure 3 gives a comparison of the computed and actual changes in the thawing layer. The computations correspond quite well to the observations. The fact that the snow disappeared somewhat more slowly than according to the computations can evidently be attributed to the fact that liquid precipitation was not taken into account in the computations.

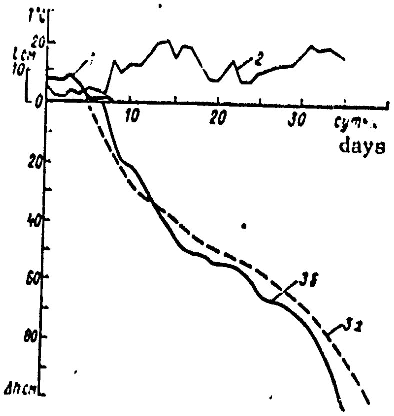

Fig. 3. Soil thawing (Mozhaysk meteorological station, 2 April - 6 May 1972). 1) snow thickness, 2) air temperature, 3) thickness of the thawing layer (a -- computations, b -- observations)

In general, it can be stated that the proposed method makes possible quite precise computations of soil thawing and can be used in determining the quantity of moisture accumulated by the soil.

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RELATIONSHIP BETWEEN DISTANT TRANSMIGRATIONS OF INSECTS HARMFUL FOR AGRICULTURAL CROPS AND ATMOSPHERIC PROCESSES

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Abstract: On the basis of use of data on cyclonic systems and atmospheric fronts the authors demonstrate the possibility of predicting distant transmigrations of insects harmful for agricultural crops and the regions of their mass settling are determined. The article characterizes ways to solve this problem on the basis of many-sided cooperation between the Plant Protection Service and the USSR Hydrometeorological Service.

[Text] Agriculture in all countries experiences enormous losses from pests and diseases of agricultural crops. The development of most branches of plant cultivation is unprofitable without special work on plant protection. There must be a scientifically sound prediction of the resettling, condition and number of harmful organisms in order to formulate rational ways to prevent damage and to plan expenditures on plant protection. It is particularly difficult to predict those species which are capable of prolonged movements over great distances. Their migrations lead to enormous concentrations of pests and the infliction of serious losses in agricultural production.

Accordingly, it becomes necessary to foresee in advance the probability, time and direction of transmigrations of harmful insects and the causative agents of diseases, to determine the regions of their increased concentration and the possibility of further development in landing places. A knowledge of these parameters makes it possible to ensure timely organization and routine implementation of a system of measures for optimizing phytosanitary conditions.

In our study of the patterns of transmigrations of harmful insects as the model object we used the beet webworm, a dangerous polyphageous pest which occurs widely in the principal agricultural regions of the country. The nature of the behavior, resettling and reproduction of this species are dependent for the most part on the state of environmental hydrothermal factors. It is heat- and moisture-loving: at a temperature below 16-17° and an inadequate environmental moisture supply there is a marked decrease in fertility and population, remaining harmful only at foci with favorable microclimatic conditions: at a temperature above 19°C and a humidity-temperature coefficient greater than 1.0 there is a rapid restoration of numbers and a threat of universal mass reproduction is created. Depending on the habitat and the weather conditions in the growing season the beet webworm can develop in 1-3 generations. The adult stage of the insect -- the butterfly -- is capable of transmigration; the damage is caused by the caterpillars, especially those of intermediate and older ages [2, 3, 7].

A clarification of the factors responsible for the mass movements of the beet webworm demonstrated that they usually occur when there is an intensive multiplication of the pest and are closely associated with synoptic processes in the atmosphere. The influence of weather differs in dependence on the transmigration phase.

The first phase is the rising of the butterflies into the air and their flight around within the limits of the center of reproduction (in a radius up to 25 km) is favored by anticyclonic weather with a predominance of clear days or days with few clouds with a wind velocity not greater than 5 m/sec. The rising up of the butterflies is stimulated by a search for optimum thermal conditions. It is observed primarily at twilight and at nighttime, with a decrease in temperature of the surface air layer to 13° C, and also in the near-midday hours, when it rises above 30°C. Due to the infrequent falling of precipitation in an anticyclonic system the maturing of butterflies under these conditions is retarded and often it ceases entirely, causing their complete infertility.

The second phase is distant flights of the beet webworm, associated with its movements into other regions. The flight of the butterflies is with the wind and therefore its direction usually coincides with the prevailing direction of the winds. Most of the insects fly at an altitude up to 100 m. Taking into account the variability of wind direction and velocity, relief conditions and the limited strength of the butterflies, it is assumed that in 24 hours they can fly no more than 50 km. Accordingly, transmigrations of the beet webworm over greatest distances are favored by a stable nature of the weather with a relatively constant direction of the winds. However, since the transmigration of the butterflies also occurs in the higher layers of the atmosphere, not rarely without their active participation, these concepts require further refinement.

The final phase of the transmigration -- the settling of the beet webworm within the limits of a new territory -- occurs under conditions of a cyclonic type of weather. A considerable cloud cover and prolonged falling of rain, primarily of the continuous type, greatly limit the resettling of the butterflies, facilitate their considerable concentration and fertility and favor their subsequent development and reproduction. This process is manifested most clearly in extensive, slowly moving cyclones, for the most part in their central parts and in the zone of a warm front.

Thus, knowing the meteorological conditions causing the beginning of distant flights of the beet webworm and their cessation, and also the paths and speeds of movement of air currents in the atmosphere, it is possible with an adequate degree of accuracy to foresee the probability and time of transmigration of the insect pest in individual regions of the country [1, 3, 5, 6].

However, checking of these determined dependences and recommendations for their use in the practice of plant protection have been complicated by the prolonged depression of the beet webworm, which continued for more than 30 years. This became possible only during the last decade in connection with a new wave of mass reproduction of the pest. It achieved its greatest scale in 1975 when over an extensive territory of the Northern Caucasus, the Central Chernozem region, the Volga region and in the eastern oblasts of the Ukrainian SSR there was everywhere a great population of the beet webworm, and in individual centers it defied evaluation. In these regions during the flight period of the first generation of the pest (second and third ten-day periods in June) there was a predominance of hot and dry weather. The air temperature during the daytime hours daily exceeded 30°C but at nighttime dropped to 10-15°C or below. The precipitation, most frequently brief, fell once or twice during the 10-day period and constituted not more than 50% of the norm. Such conditions favored the rising of the butterflies into the air and their active flight.

The predominance of an easterly flow, created by the periphery of the anticyclone persisting for a long time over Kazakhstan and the southeastern European part of the country, caused the movement of the butterflies into the western and southwestern regions of the Ukrainian SSR and the Moldavian SSR, where during a prolonged period of time a cyclonic pressure field was maintained. Frequent (6-7 times in a 10-day period) and abundant (150-250% of the norm) precipitation in these regions caused the mass settling of the butterflies and their concentration in enormous numbers, especially in the zone of atmospheric fronts. These same conditions ensured a high fertility of the butterflies and favorable conditions for the feeding of the caterpillars, as a result of which there was considerable damage to the crops and a decrease in their productivity.

An evaluation of the situation developing in 1975 confirmed that the main reason for the distant flights of the beet webworm must be regarded as a definite combination of weather conditions developing under the influence of cyclonic systems and fronts. An analysis of these processes made it possible to establish the possibility of preparing short-range predictions of transmigrations of the pest and determining the places of its mass concentration and harmfulness. Since the appearance of damaging caterpillars usually occurs not less than 10 days after the flight of the butterflies, such an advance warning is entirely adequate for the timely preparation of field agencies for carrying out protective measures.

For the purposes of practical realization of these ideas a relationship has been established between the operational agencies of the Plant Protection Service and the prognostic subdivisions of the State Committee on Hydrometeorology. An agreement has been concluded on creative cooperation between the All-Union Scientific Research Institute of Plant Protection and the Northwestern Administration of the State Committee on Hydrometeorology. As a result of their joint activity a system has been developed for drawing up a forecast of transmigrations of the beet webworm. It is based on the detection of regions of the mass concentration of butterflies, an analysis of the synoptic situation within the limits of these territories during the last 10-15 days, and also evaluations of weather conditions at the locations of the surmised resettling of the beet webworm, taking into account their probable changes in the immediate future. Such predictions were made in 1976 and 1977.

For example, in 1976, in connection with the extensive resettling and good initial state of the beet webworm, there was expected to be a mass reproduction of the pest and a possibility of its distant flights. However, unstable cool weather with marked fluctuations in temperature and the frequent falling of precipitation during the course of almost the entire spring-summer season sharply reduced the intensity of multiplication of the pest in most of its habitats. Such a nature of the weather also did not favor high rising of the butterflies or their prolonged transmigrations. Centers of increased density of the pest persisted for the most part only in the southern European part, but the possibility of its resettling from these regions was restrained by the prevalence of winds of northerly directions. Taking into account the developing situation, distant transmigrations of the beet webworm were not foreseen in the forecast. At the same time, it was pointed out that during individual periods with warm dry weather and winds of southerly and easterly directions the flight of butterflies about the area was probable, but due to the brevity of favorable weather conditions the radius of their flight would be insignificant. Such local migrations, in accordance with the forecast, were noted, for example, during late June and during the first ten-day period of July in the territory of the Northern Caucasus.

During 1977, during the period of development of the beet webworm in the European USSR, there was a predominance of moderately warm weather with precipitation falling everywhere and with winds of variable directions. Such conditions ensured the normal development of the pest and did not necessitate its transmigration over great distances. Insignificant movements of butterflies of the generation which had survived over the winter were predicted only for brief periods of dry weather with winds of easterly direction and were observed in late April and the first days of May from regions along the Lower Volga into Rostovskaya Oblast.

Favorable conditions for distant transmigrations of the beet webworm developed in 1977 within the limits of the Asiatic part of its range. During the period of flight of butterflies of the generation which had survived the winter (first half of June) over a great expanse of Western Siberia and Kazakhstan there was hot, primarily dry weather with brief rains of local importance and a predominance of easterly and northeasterly winds. This favored the extensive flight of the beet webworm and the intensive transport of its butterflies in a westerly direction. Their mass settling, as expected, occurred in the territory of the Southern Urals, Western Kazakhstan and the Middle Volga, where the frequent and abundant falling of precipitation was observed. As a result, the population of the beet webworm in the mentioned regions was considerably greater than could be supposed judging from the numbers of the pest surviving the winter.

An anticyclonic nature of the weather also persisted in the Asiatic territory during the time of flight of first-generation butterflies (second half of July); this also ensured the possibility of their transmigration over great distances. However, stable hot dry weather favored infertility of the beet webworm and a reduction in its population, as a result of which the flight strength of the butterflies was insignificant. Passing rains in individual regions of Kustanayskaya and Chelyabinskaya Oblasts caused some increase in the intensity of pest flight, but since its population was small, the transmigrations, as predicted, were not of a mass character.

Predictions of the probability of transmigrations of the beet webworm were made available to the USSR and RSFSR Ministries of Agriculture and the All-Union Academy of Agricultural Sciences. They made possible a timely orientation of the Plant Protection Service on the need for carrying out preventative and extermination plans.

At the same time, for a deeper study of the patterns of beet webworm transmigrations and extensive automation of the process of collecting the necessary information, joint investigations have been begun by the Main Geophysical Observatory and the All-Union Institute of Plant Protection on the possibility of using meteorological radars for these purposes. Under experimental conditions it was possible to determine the physical parameters of the butterflies and the fundamental possibility of their detection by radar apparatus. Taking into account the collected data, technical prerequisites were formulated for detecting the movements of insects using meteorological radars and methods were developed for measuring the principal indices of their flight: altitude, speed, direction, reflectivity, etc.

Such work is being carried out in our country for the first time. It is making possible a changeover to modeling of the flight dynamics of the beet webworm and determination of the principal links determining the singularity of this process in dependence on the state of the pest and physical-synoptic conditions in the atmosphere. In the future the formulated concepts and methodological principles will be tested for predicting the transmigrations of other migrating species of insects damaging agricultural crops. This will make it possible to improve the overall system for the planning and organization of protective measures. The solution of such a complex problem is possible only on the basis of multisided cooperation between the Plant Protection Service and the USSR Hydrometeorological Service.

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UDC 551.46.086

SELF-CONTAINED RADIO WAVE METER FOR HYDROLOGICAL SUPPORT OF MARINE DRILLING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 110-113

[Article by Candidate of Technical Sciences Yu. F. Masterov, All-Union Scientific Research Institute of Marine Geology and Geophysics, submitted for publication 11 January 1978]

Abstract: The article describes a radio wave meter for measuring, and transmitting via a radio channel, data on the height and mean period of a wave in the coastal zone of seas. The radio wave meter is designed for routine hydrological support of geological prospecting and other work at sea.

[Text] The specific nature of drilling work, usually carried out from small floating bases on different parts of the shelf, in regions where usually there are no hydrometeorological posts, imposes additional requirements on the means and methods for measuring wave parameters. The principal objective in hydrological support of drilling at sea is the regular routine supplying of all drilling crews with information on waves. This information must be convenient for interpretation without additional instrumental and mathematical processing and the wave meters themselves are reliable, mobile and must ensure automatic measurement, processing and transmission of the generalized statistical characteristics in the system of dispatcher radio communication of a geological expedition [4]. Among the types of wave meters known in our country for the above-mentioned purpose we can recommend only several instruments, such as the GM-61 coastal recording wave meter [1] and the GZ-2 self-contained radio wave meter.

The GZ-2 radio wave meter was specially developed for solving problems in the hydrological support of geological reconnaissance work at sea. It makes it possible to measure and transmit, through a radio channel, the mean characteristics of waves in digital form. Special receiving apparatus is not required. Information is received directly by ear from the loud speaker of a standard geological radio station of the "Karat-M" type. The processing of measurements, determination of the mean characteristics of waves, coding of information and its transmission through the radio channel is accomplished in an autonomous unit with the aid of simple digital electronic devices using the following algorithm: determination of the time t of passage of 128 waves and the sum S of the heights of these waves; automatic division of t and S by the number of waves; transmission of two groups of sound pulses (signals) through the radio channel. The number of pulses in each group is proportional to the mean wave height h_{mean} and their mean period T_{mean} respectively.

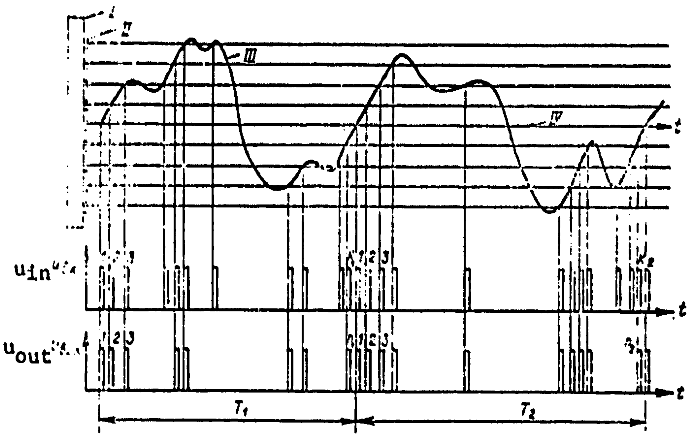

Fig. 1. Time diagram of operation of pulse converter. I -- beacon; II -- contact; III -- wave profile; IV -- mean sea level, U_{in}, U_{out} are the voltages of the input and output signals of the memory triggers, k_i, n_i are the numbers of the closings of the contacts and closed contacts during one period T_i.

As the wave sensor in the radio wave meter we used an electric contact beacon. Using a pulsed converter, designed in the form of triggers connected to each beacon contact, any closing of a contact by the water is converted into a counting pulse. The function of blocking of repeated counting pulses from each contact during a wave period is performed by memory triggers connected in series with the converter triggers. Thus, the height of an individual wave is converted into a number of memory switchings proportional to it. In this way there is exclusion of the secondary wave fluctuations above (below) mean sea level. Figure 1 shows a diagram of converter operation.

A device for setting the memory triggers in a zero position and a wave counter are connected to the contact situated near mean sea level for the registry and counting of individual waves.

The summing of the number of switchings of the memory triggers and determination of the time of passage of the 128 measured waves is accomplished in the reversible height and time counters respectively which are present at the two inputs for addition and subtraction. A cadence pulse generator is connected in this case to the summing input of the time counter during the time of the measurement.

The automatic division of the sum S and the time t by 128 waves, coding and transmission of the mean height and period of the wave through the radio channel is accomplished by connecting the pulse generator to a sound signal chopper for the radio station and simultaneously to the subtracting input q_1 -- the trigger of the heights counter or q_2 -- the trigger of the time counter (where $q_1 = 1, 2, 3, \ldots, j$ and j is the number of triggers in the counter). Then, with setting of all the memory triggers in a zero position, for example, the heights counter, the chopper operates K_1 times. It is easy to note that

$$h_{mean} = \frac{b\,2^{q_1}}{128} K_1,$$

where b is the beacon interval in meters.

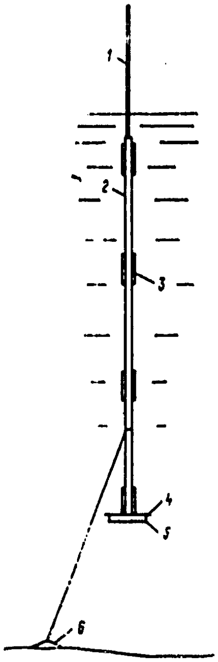

Fig. 2. Floating buoy. 1) mast; 2) section; 3) connecting piece; 4) damping disk; 5) weight; 6) anchor

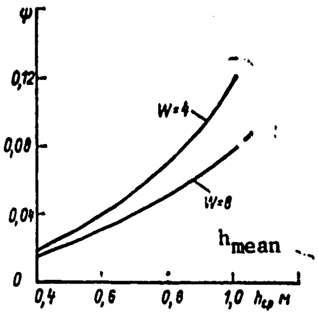

Fig. 3. Change in probability of appearance of error with different counter capacity.

Similarly we determine the mean wave period:

$$T_{mean} = \frac{\tau 2^{q_2}}{128} K_2,$$

where K_2 is the number of switchings of the chopper and accordingly the number of sound signals transmitted through the radio channel during the readout of information from the time counter; τ is the period of the cadence pulses.

The required accuracy of final information is governed by the choice of numbers of the triggers q_1 and q_2, the distance b, the period τ and the number of measured waves. But this accuracy cannot be greater than the accuracy in determining the mean height and mean period of the wave by the considered instrument. As demonstrated in [2], the error in determining mean wave height is

$$\delta = \left[\frac{c^2 + \left(\frac{b}{2\,h_{cp}}\right)^2}{128}\right]^{\frac{1}{2}} + \frac{F_{2a}\left(1 - \int\limits_0^{2a} RpdR\right)}{2\,(1 - F_{2a})},$$

where

$$F_{2a} = 1 - \exp\left[-\frac{\pi}{4}\left(\frac{2\,a}{h_{cp}}\right)^2\right];$$

$$p = 1{,}57\,R\exp\left[-\frac{\pi}{4}\,R^2\right];$$

$$R = h_i/h_{cp};$$

[cp = mean] c = 0.5 is the variation coefficient for wind waves; a is the distance between the contact, regarded as the zero distance, and mean sea level.

With $h_{mean} > 0.4$ m, b = 0.2 m, $\delta < 0.06$.

Taking the cited error into account, the increment in wave height for one sound signal must not be less than 3 cm. For practical purposes it is more convenient that this increment be a multiple of 5 cm (5, 10, 15 cm).

For example, with $q_1 = 5$, $q_2 = 5$, b = 0.2 m and $\tau = 1$ sec

$$h_{mean} = 0.05K_1 \text{ (m)}, \quad T_{mean} = 0.25K_2 \text{ (sec)}.$$

It should be noted that the repetition rate of the sound signals, as demonstrated by experience in operating the GZ-2 under field conditions, must not exceed 1 Hz. Such sound signals are easily discriminated and counted by ear from the loudspeaker of the radio receiver when there is a high interference level. The chopper and generator of counting pulses are connected by a programming mechanism upon ending of the period of averaging of the measured waves.

The high noise immunity of the adopted coding system when there is a sensitive receiving antenna ensures a considerable effective range for the reliable radio reception of information from the GZ-2. For example, when using a radio station of the "Karat-M" type as the radio transmitter, the range of telemetric communication attained 50 km.

In order to prepare the user for the reception of wave data, prior to each contact with the GZ-2, the intervals between which were selected as either one or three hours, a preliminary sound signal with a duration up to 16 sec is fed through the radio channel.

When placing the GZ-2 apparatus at depths greater than 20 m the support used is a Froude buoy [6]. Such a buoy is a long hollow tube (Fig. 2) fabricated of AMG-6 light aluminum alloys. The tube is assembled of a set of hollow sealed cylindrical sections with connecting pieces. A damping disk is mounted on the lower end of the buoy in order to decrease the period of natural oscillations. The useful lift of this buoy in the case of a metacentric height of 2 m and with wave heights up to 6 m is 10-15 kg. The total mass of the buoy does not exceed 100 kg.

At depths up to 10 m the self-contained part of the GZ-2 is placed in a container mounted on the top of a column of casing pipes drilled into the bottom. As demonstrated by sea tests, such supports have withstood wave loads for a period of 2 or 3 years. In seas with a variable mean level the radio wave meter, mounted on a fixed support, is supplemented by a unit for automatic determination of contact with mean sea level. The unit contains a number of counter-"and" logic pairs corresponding to the number of buoy contacts present in the zone of change in tide height or height change induced by the wind. The counter of each pair counts the closings from a definite buoy contact, whereas the last trigger of the counter controls the pair "and" logic, being a shutter for the transmission of pulses registering the closing of tide contact into the wave counter.

When measuring real waves, due to their irregularity, it is more likely that there will be opening of that "and" logic which is controlled by the counter counting the water closing of the contact situated near the mean sea level.

The unit for determining the mean level contact, together with the time relay, can be used as a device for cutting off the self-contained unit during a calm in order to save current. Thus, if any of the counters is not completely filled during the time mT_{max} (where m is counter capacity, T_{max} is the maximum wave period), the current is automatically cut off.

In order to determine the optimum capacity of the counter m we carried out analytical computations and field tests. It is obvious that the greater the m value, the more precise is the determination of the zero contact and the greater is the increase in the required power for the self-contained unit. Accordingly, it was necessary to determine the minimum capacity of the counter which would ensure the admissible measurement accuracy.

In regarding the closings of definite contacts as independent measurements we recall that according to the theory of irregular waves there is a mathematical expectation of individual rises in the wave-covered sea surface. This also means that there is a confidence coefficient such that the position of the wave-covered surface will fall in the range x±a (where a is the confidence evaluation). If the position of mean sea level is used as the origin of the reading, then $x = 0$.

The authors of [2] examined the error in determining the mean height of the waves, governed by a noncorrespondence between the position of the zero contact and the assumed mean sea level. The accuracy was considered to be satisfactory if the distance between the zero contact and the mean sea level is not greater than 0.2 m.

Thus, for evaluating the reliability in determining the mean level contact with a stipulated accuracy in measuring the mean height of waves h_{mean} it is possible to limit ourselves to a confidence evaluation of less than 0.4 m. Obviously, in the case of a wave height less than 0.8 m there is closing either of the contact situated near the mean level or the contact adjacent to it. Then, using the formula from [3]

$$m > \left[\frac{t(p)}{a}\right]^2 \sigma^2,$$

where t(p) is a function of the confidence coefficient p, σ is the standard deviation, equal for well-developed waves to 0.4-0.56 h_{mean} [5].

If $p = 0.95$ and h_{mean} is less than 1 m, then $m = 6$. Field tests of the unit for determining the mean level were made with a counter capacity $m = 4.8$.

An incorrect determination of the mean sea level contact by the measuring unit was regarded as an error. The error frequency was determined from the ratio of the number of errors to the total volume of the tests. Figure 3 shows curves of the dependence of error frequency in operation of the mean level unit on mean wave height. A change in m from 4 to 8 with wave heights up to 1 m exerted no significant influence on increasing the accuracy in determining mean sea level. Some discrepancies were noted in the case of wave heights greater than one meter.

We note in conclusion that the limits in measuring mean wave height with a radio wave meter is 0.2-0.8 m, for the mean period -- 0.25-16 sec; the independent period of operation is up to one month; the error in determining mean wave height is less than 6%.

The described radio wave meter can be employed in the hydrological support of different kinds of work where it is necessary to obtain regular and routine information on waves.

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UDC 551.50:656.61:639.206

SCIENTIFIC-OPERATIONAL HYDROMETEOROLOGICAL SUPPORT FOR THE FISHING INDUSTRY AND THE MERCHANT MARINE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 114-118

[Article by Candidate of Geographical Sciences F. S. Terziyev, State Oceanographic Institute, submitted for publication 4 April 1978]

Abstract: This article is devoted to the problems involved in organization and effectiveness of hydrometeorological support of the fishing industry and merchant marine. The rational use of data from shipboard observations, aerial reconnaissance, observations at shore stations, all these yield an appreciable economic effect (40 million rubles annually from the servicing of the fishing fleet alone by synoptic groups). An important role in the hydrometeorological servicing is played by the development, by the institutes of the State Committee on Hydrometeorology, of methodological principles for predicting natural phenomena, both those dangerous for the fishing fleet and those exerting an influence on physicochemical and biochemical processes in the water medium which exert a direct influence on links in the biological chain of the world ocean, as well as the preparation of regime-reference manuals for fishing regions.

[Text] Scientific-operational hydrometeorological servicing of man's economic activity is arising and developing under the influence of practical need, the requirements of production. In turn, hydrometeorological servicing, including, in particular, extensive hydrometeorological information, scientific forecasts and sound computations, is itself beginning to exert an influence on production and is becoming a component part of it.

The work of the fleet, enterprises and organizations of the fishing industry, modern methods for carrying out the search for and exploitation of fish and other sea products are in direct relationship and dependence on the state of the medium, hydrological and meteorological factors, frequently being decisive. In connection with the growth and development of the ocean fleet, the exploitation of new fishing regions, poorly studied in hydrometeorological respects, situated hundreds and thousands of miles from shore bases and ports, the use of diversified and complex catching gear and procedures, the hydrometeorological support of the fishing fleets and expeditions by weather bureaus has become exceedingly difficult, of a low level of effectiveness, and frequently even impossible. Conditions have required new, more modern forms and methods for the hydrometeorological support of the fishing expeditions and fleet.

Synoptic groups servicing the merchant marine and fishing expeditions in the northern seas and the Atlantic were organized in 1950 aboard the ships and floating bases departing for work from Murmansk [26]. In the late 1950's the servicing of fishing expeditions in the North Sea and in the Norwegian Sea by such groups began. In 1960 a synoptic group was dispatched from Petropavlovsk-Kanchatskiy for servicing the fishing fleet in the northern part of the Pacific Ocean, the Sea of Okhotsk and the Bering Sea [31]. In 1961 a synoptic group from Vladivostok serviced the catching of cololabis and herring in the southern Kurile Islands [20]. This was followed by the servicing of expeditions in Antarctic waters by synoptic groups from Klaypeda, Kaliningrad and Odessa. Later the groups were enlarged and an oceanologist was included; they were outfitted with modern receiving-transmitting and facsimile apparatus and are being transformed into large floating hydrometeorological bureaus. The experience of the first synoptic groups was extended to all regions of the open seas and oceans where the fishing expeditions of the Soviet Union work. During recent years the servicing of ships in the fishing industry and fleet is also carried out by synoptic groups based on scientific research weather ships in the Atlantic [14].

Most of the fishing regions of the world ocean are characterized by severe hydrometeorological conditions. For example, in the North Atlantic the mean frequency of recurrence of storm winds with a velocity of 15 m/sec or more during the winter is more than 40%; the continuous duration of a storm attains 3-4 days, the wind velocity attains 50 m/sec and the wave height attains up to 25 m [6]. Many fishing regions of seas in the northern basin and the North Atlantic (Barents Sea, Greenland Sea, Davis Strait, Labrador shelf, etc.) a considerable part of the year are locked in heavy ice [17], are in a zone of moderate and heavy icing. As a whole, over the water area of the fishing regions of the northern seas and the North Atlantic during the year there are 80 or more particularly dangerous hydrometeorological phenomena for ships of the fishing industry and fleet.

The fishing regions of the Bering Sea, Sea of Okhotsk and Sea of Japan and the northern part of the Pacific Ocean are also characterized by intensive cyclonic activity; the average for the year here is more than 120 cyclones and about 20-22 typhoons. In the Bering Sea and Sea of Okhotsk and along the shores of Alaska during the winter season there is an exceptionally heavy icing, leading to ship damage and destruction. In these very same regions fishing is made difficult by floating ice.

Floating antarctic ice and icebergs during winter in the entire antarctic zone reach 50°S and constitute a serious danger for fishing in these regions.

All this puts the hydrometeorological servicing of fishing expeditions in the open sea in the ranks of the most important tasks of the USSR State Committee on Hydrometeorology and Environmental Monitoring.

At the present time there are 6-11 synoptic groups operating simultaneously in different parts of the world ocean. They are servicing hundreds of fishing ships. Each group consists of 5 to 7 persons. During the course of the day the forecaster and the oceanologist repeatedly consult the fishing director and the conference of captains, where the matter of the disposition of the fleet is discussed and solved. Each year the synoptic groups and the weather bureaus carry out the servicing of runs made by floating docks, floating cranes and convoys of vessels with a short navigational range, many of which must travel great distances from Europe to the ports of the Far East, Atlantic, etc.

For successful work of a synoptic group use is made of all the hydrometeorological and synoptic material received from Soviet and foreign centers in the particular region: surface charts for all the observation times, pressure pattern charts, information on tropical cyclones, etc.

The successful hydrometeorological servicing of the fishing industry is also favored by the great amount of work carried out by the administrations of the State Committee on Hydrometeorology and institutes on the organization of an observations service and expeditions.

Already at the beginning of the century Nikolay Mikhaylovich Knipovich wrote that without the organization of large special sea expeditions and regular voyages, which must be developed quantitatively and qualitatively, without an adequate study of environmental conditions and the totality of phenomena transpiring in the atmosphere, hydrosphere and in space in their unity, interdependence and intercausality, the rational use of natural resources is unthinkable.

Due to the great amount of work carried out by the State Committee on Hydrometeorology and the agencies of the fishing industry and fleet, we have more than 1,800 shipboard stations without standard observers, half of which are based on fishing and reconnaissance vessels of the fishing industry. They carry out observations and transmit to different data collection centers the results of more than 2,000 observations per day from different regions of the world ocean frequently completely uncovered by hydrometeorological observations. And although this information is exceptionally valuable for hydrometeorological and fishing science and practice, we still have not done everything for it to be complete, that it be of a high quality and that it be received on time. For example, most ships for different reasons transmit summaries for the nighttime observation times with a lag up to six hours. The observations from some ships are of a low quality.

For many years now all hydrometeorological agencies have made extensive use of photographs from our earth satellites for more precise determination of the location of pressure centers, in frontal analysis, and in detecting the presence of fog and precipitation. Satellite information is of great importance in evaluating ice conditions and determining the edge of the ice in northern and Far Eastern basins.

During recent years in almost all basins specialists have been carrying out measurements of surface temperature of the sea using a radiation thermometer from an aircraft incidentally with the carrying out of ice reconnaissance and determination of the position of the ice edge [28]. The frequency of the flights and the position of the runs are determined for the most part by fishing and transport objectives and also by the goal of obtaining regime characteristics, computations and predictions of the thermal structure of surface waters, prediction of the onset of ice phases and the position of the ice edge. Specialists have developed and are successfully using a method for computing the temperature of the surface and surface layer of seas on the basis of materials from aerial thermal surveys [10].

Joint flights of workers in the fish reconnaissance service and shipboard hydrologists of the State Committee on Hydrometeorology are the practice; this makes possible the timely introduction of corrections into the organization of search for the catching of schools of fish and gives a great economic effect. For example, in the Far East, in the Kurile-Hokkaido region, this method for the search for fish in a number of cases made it possible to increase the productivity of fishing by a factor of 2-3. In some cases the data from such reconnaissances make it possible to prolong the voyage and navigation season.

For the servicing of the fishing industry extensive use is made of information from our scientific research ships, which operate in all northern and Far Eastern seas, the Atlantic and Pacific Oceans. Standard and "secular" sections for determining the dynamics of the principal currents, fronts, etc. are of inestimable importance. For more than 80 years there have been regular observations of the hydrological section along the Kola meridian in the Barents Sea; these are being used successfully in preparing many meteorological, hydrological and fishing forecasts.

The high requirements imposed by the fishing industry agencies on our information and servicing are forcing hydrometeorologists to work on constant reconnaissance. For example, the multisided hydrometeorological servicing of the fishing fleet in the Labrador region, first initiated by specialists of the Murmansk Administration of the Hydrometeorological Service in the late 1960's-early 1970's, using synoptic groups, a ship performing the role of an "ice patrol," and a helicopter for ice aerial reconnaissance, is finding broad use in other fishing regions. For example, the economic effect from work of the ice patrol in the Bering Sea from January through May, obtained as a result of a knowledge of ice conditions and the saving in fishing time, is about 2 million rubles [21].

The success of work of the synoptic group is determined by the fact that being with the fleet, the weatherman and the oceanologist concentrate their attention, among the entire diversity of hydrometeorological factors characterizing the weather and the hydrological regime, on the ones which are the most important, exerting the greatest influence on the results of fishing and the safety of navigation (wind, waves, icing, water temperature, ice conditions and deterioration of visibility). A knowledge of the actual and predicted weather and extensive information on hydrometeorological and ice conditions in this region enable the fishing director to plan correctly the operation of the fleet, on a routine basis, with a knowledge of the actual conditions, to project its relocation, and to achieve a high effectiveness of fishing.

The total economic effect from servicing of the fishing fleet of our country by synoptic groups is increasing annually and is about 40 million rubles, which is several orders of magnitude greater than the expenditures on the maintenence of the synoptic groups. And it is entirely natural that great attention is devoted to this problem in the draft of the national program on oceanology for fisheries.

Hydrometeorological servicing carried out from ashore has not lost its importance.

The leading workers and specialists of the hydrometeorological service, weathermen and oceanologists are participating in the work and are presenting reports at the fishing councils of fleets, combines and ministries.

In the fishing councils a decision about the redisposition of the great fleet, dispersed in many seas and oceans, is made taking into account the anticipated hydrometeorological conditions.

For example, each day for marine and fishing organizations of the northern basin specialists prepare about 80 forecasts and warnings which are sent to 270 addresses. They also prepare forecasts and consultations at the request of captains of ships, the directors and dispatchers of fleets; each day they are sent out to more than 2,000 addresses.

The agencies of the State Committee on Hydrometeorology have data on the disposition of the fleet; this makes it possible, differentially, to issue forecasts, warnings and consultations for individual squares in the sea, taking into account the type of fishing and the navigation region. The opinion of the weathermen and oceanologists are of decisive importance in determining the order of movement of the ships, the choice of the route to be taken, the places for refuge and the most favorable time for carrying out the work. Great attention is devoted to the servicing of sea ports, where there is a concentration of a great number of ships and there is an enormous flow of freight; here the storm warning service is particularly well organized.

In the event of receipt of a hurricane warning, special measures are taken in the port for the tying-up of ships at wharves, the watch aboard ships is strengthened, and the captains and fleet directors are called by radio, television and ship's telephone. During the last 10 years a total of 120 strong storms have been observed in ports along the shores of the northern basin. They were all predicted a sufficient time in advance, making it possible to avoid possible losses and to register a conditional economic effect of about 18 million rubles.

During recent years the servicing of ships with the most advantageous navigtion routes through the ocean in dependence on hydrometeorological conditions has gained great popularity among navigators. The basis for this method is, taking into account forecasts of weather and hydrological conditions in the ocean, for several days in advance to compute such a route on which the ship will experience a minimum loss of speed [4, 5]. The number of vessels using the recommendations of the State Committee on Hydrometeorology is systematically increasing. In the world ocean each year about 3,000 ships of the USSR are serviced by recommended courses; this gives a savings of from 7 to 10 hours travel time per voyage and the total economic effect is up to 3.5 million rubles per year.

In the practice of servicing of the fishing industry and fleet, during recent years there has been continuous around-the-clock transmission of forecasts and storm warnings by special radio stations in Murmansk, Odessa, Yuzhno-Sakhalinsk and other ports. The watch navigator at any time of day can switch on his radio receiver and learn the weather, hydrological and ice conditions in the fishing region, along the navigation route or in the port of destination.

An effective hydrometeorological support of the fishing industry in the oceans and seas is attained when there is a good scientific-methodological base.

One of the principal tasks of scientists of the Hydrometeorological Service is the formulation of methodological principles for the prediction of hydrometeorological phenomena, and in particular, phenomena which are dangerous and particularly dangerous for the fishing industry and fleet, as well as the preparation of different regime-reference manuals on present-day and promising fishing regions.

A number of scientific investigations have been devoted to study of the dynamics of the atmosphere determining the laws of formation and distribution of cyclones, typhoons, storm-driven waves, icing of ships, position of the ice edge and icebergs. For example, during recent years specialists have developed a synoptic-statistical method for predicting the movement of typhoons in Far Eastern seas for a period of 1-3 days [23] and physical-statistical methods for predicting storm winds in the North Atlantic and other fishing regions [22, 25].

On the basis of the spectral theory of waves and generalization of numerous data from instrumental observations it has been possible to refine existing and develop new methods for computing and predicting wave fields [12, 24], in particular, for the North Atlantic, Barents Sea, Norwegian Sea and Greenland Sea.

A detailed study has been made of the physical conditions for the appearance of the icing of ships [13, 15]. Synoptic and numerical methods have been developed and introduced into practice for predicting icing in the north polar regions [13, 19]; these are being employed successfully for issuing warnings to fishing expeditions and ships, this making it possible to prevent the entry of ships into zones of icing and to avoid damage.

Important investigations of the ice regime were carried out for the fishing regions of the Northwestern Atlantic, Barents Sea, Greenland Sea, Bering Sea and the Sea of Okhotsk. Methods for the long-range forecasting of the total ice content and position of the ice edge for these regions and the extremal boundaries of distribution of icebergs were determined; computed models of ice drift in dependence on hydrometeorological conditions were obtained [7, 17]. Experimental investigations are being carried out to determine the dynamics of the ice cover with the use of modern technical means and methods.

Effective fishing and the safety of navigation are determined to a considerable degree by visibility conditions, especially in regions with a great concentration of fishing ships. On the basis of experimental investigations a study was made of the physical conditions of formation of sea fogs and methods have been developed for predicting them [32], as is also the case for evaporation fogs in northern seas [27]. The economic effect is more than one million rubles simply as a result of warnings of the appearance of evaporation fogs for the fishing industry in the northern basin during winter.

The success of fishing is dependent to a considerable degree on the physicochemical and biochemical processes transpiring in the water medium, which exert a direct influence on intermediate links of the biological chains in the world ocean. In these processes an important role is played by water temperature, characterizing the habitat of commercial fish. Investigations of the horizontal and vertical structure of the temperature fields in sea water make it possible to detect thermally homogeneous water masses and to ascertain the position of hydrological fronts and the boundary of the seasonal thermocline.

A study of formation of water temperature fields, development of methods for predicting the thermal state of the sea, and determination of relationships to fishing can be found in a great number of publications of the institutes of the State Committee on Hydrometeorology, the USSR Ministry of

Fisheries, Leningrad Hydrometeorological Institute and other organizations [3, 11, 16, 18]. These investigations are based on extensive multisided experimental studies, also carried out within the framework of national and international programs: "POLEKS," "BERING," "TROPEKS," "DIGMA" and others. The State Committee on Hydrometeorology is taking an active part in these programs and is carrying out independent research in this direction.

A series of practical reference manuals has been prepared for fishing and navigation. For example, the USSR Register has published the reference book VETER I VOLNY V OKEANAKH I MORYAKH (Wind and Waves in the Oceans and Seas) [6]; it contains the most complete information on the frequency of recurrence and guaranteed probability of wind velocities and wave heights in the world ocean. The work of prognostic agencies is also based on wave and wind atlases [2] published by the Hydrometeorological Service in a common format and covering the principal fishing regions. Atlases of dangerous and especially dangerous hydrometeorological phenomena are being prepared for these same regions. They will give the stochastic characteristics of the wind, waves, icing of ships and ice conditions. Provision has also been made for the issuance of a series of atlases of standard synoptic situations determining especially dangerous hydrometeorological phenomena in the northern parts of the Atlantic and Pacific Oceans, in northern and Far Eastern seas.

We feel that the specialists of the State Committee on Hydrometeorology and the USSR Ministry of Fisheries must work out long-range plans for the preparation, publication and adoption of hydrometeorological manuals in accordance with the long-term plans for the development of fishing.

The State Oceanographic Institute and a number of other institutes at the present time are refining the list of requirements on the accuracy, discreteness, ranges and other characteristics of parameters which must be measured aboard scientific research ships. The institutes of the Ministry of Fisheries must also be involved in this work.

On the basis of modern concepts concerning the significant nonstationarity and variability of oceanographic fields (fluctuations in the thermocline, stratification and inhomogeneity) it is desirable to determine the requirements imposed on oceanographic measurements along profiles in fishing regions and interpretation of the collected data [1, 8, 9, 29, 30].

It must be determined whether it is legitimate to use temperature data collected along profiles several days and a week before, and especially, in the organization of reconnaissance and fishing.

In the great, multisided and complex task of hydrometeorological support of the fishing industry and fleet there are many shortcomings and unsolved problems which are constantly being worked on by groups of scientists and specialists at institutes and local administrations of the USSR State Committee on Hydrometeorology and Monitoring of the Environment.

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Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 119-120

[Book Review by Professor Ye. M. Dobryshman]

[Text] The word "nonlinear" evidently has been appearing in theoretical studies of all branches of physics more frequently than other words for several years now. This is not just fashionable; it is due to an insistent necessity for studying nonlinear processes, since they conceal the most important and fine mechanisms of complex natural phenomena. And within the well-known general "information explosion" there is a really enormously increasing number of investigations of nonlinear processes. The formulation of nonlinear mathematical models sufficiently well reflecting the physical process is a difficult problem, but its solution is necessary. On the other hand, most of the methods for solving nonlinear problems in one way or another can in essence be reduced to relatively well-studied methods for solving linear problems; "purely" nonlinear solutions are the exception and not the rule.

An analysis of the mathematical formulation of the problem must begin with an analysis of the physical essence; otherwise it is possible to "construct" a solution which will not correspond to the real physical picture. One of the methods for such a preliminary analysis is the method based on an analysis of dimensionalities. Therefore, it is entirely natural that the author devotes the first two chapters to an exposition of the general principles of the theory of dimensionalities and similarity and their applications to finding precise solutions of a number of problems in mathematical physics.

Despite the apparent ease in applying the general "formula," its formal use in problems which only slightly differ from those for which the "formula" works well can lead to unexpected results; among these is a contradiction or paradox are not even the worst.

In Chapter 3, in the example of the modified problem of an instantaneous heat source, it is shown how it is possible to solve the paradox which arises, provided there is introduction of a new concept -- self-similarity of the second kind. The sense of this concept is determined by a nonuniform limiting transition from a non-self-similar problem to a self-similar problem, that is, one in which the values of the unknown functions at different moments in time can be found by a transformation of similarity.

In the next nine chapters the author uses the introduced concept in solving different problems of both a physical and a mathematical character. In order to give some idea concerning the breadth of the problems involved and the constructiveness of the introduced concept, we will cite the titles of the subsequent chapters with brief commentaries on them (given in parentheses).

Chapter 4. Problem of a Strong Explosion With Energy Gains or Losses on the Shock Wave Front and the Problem of a Brief Impact: Self-Similar Solutions of the Second Kind.

Chapter 5. Classification of Self-Similar Solutions. (The author defines two kinds of self-similar solutions: first kind -- regular self-similarity. Here the methods of similarity theory are applicable without reservations; the second kind is irregular self-similarity. Here "self-similar" variables in a general case cannot be determined from the concepts of similarity theory).

Chapter 6. Self-similar Solutions and Traveling Waves.

Chapter 7. Self-similarity and Groups of Transforms. (The relationship to transform groups is illustrated in such classical problems as the boundary layer on a plate and rotation of a fluid in a cylindrical vessel).

Chapter 8. Spectrum of Powers in Self-Similar Variables. (The title of the chapter can be subject to misinterpretation. Reference is to the fact that in self-similar asymptotics the powers of the self-similar variables are dependent on the initial conditions).

Chapter 9. Stability of Self-similar Solutions.

Chapter 10. Self-similar Intermediate Asymptotics of Some Linear Problems in the Theory of Elasticity and Hydrodynamics of an Ideal Fluid.

Chapter 11. Complete and Incomplete Self-similarity in Turbulence Theory. Homogeneous Isotropic Turbulence.

Chapter 12. Complete and Incomplete Self-Similarity in Turbulence Theory. Flow With Transverse Shear.

In almost every chapter the materials in one section are devoted to a specific physical problem.

Thus, the concepts of intermediate asymptotics and self-similarity of the second kind introduced by G. I. Barenblatt proved to be an effective working tool for research, in seeking solutions and in interpreting an extremely broad range of physical problems.

As usual, a new concept is not always deemed to be absolutely acceptable or even unquestionable, even with respect to its name. In physics we know of those processes which after "entry" into an asymptotic regime begin their "second life," in which they have their own asymptotic form. In such a case it is also natural to call the first asymptotic form "intermediate." A clear example of this is the process of adaptation of the pressure and wind fields in the atmosphere, in the extratropical zone: after establishing a geostrophic correspondence (first asymptotic regime) all the geostrophics under the influence of the Rossby β-effect is slowly turned and drawn out along a circle of latitude (second asymptotic regime). It is a pity that the author almost nowhere uses meteorological applications other than turbulence theory.

One thing is unquestionable: the book is very useful to a broad range of investigators of linear and especially nonlinear processes in any branches of physics. The book is impossible to obtain. Therefore, in place of an entirely merited compliment to the Gidrometeoizdat for a very well produced publication of this monograph, I end with a reproach for the miserly number of copies printed -- only 2,000.

REVIEW OF MONOGRAPH BY I. V. POPOV: ZAGADKI RECHNOGO RUSLA (MYSTERIES OF THE RIVER CHANNEL), LENINGRAD, GIDROMETEOIZDAT, 1977

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 p 120

[Review by Candidate of Geographical Sciences A. V. Plashchev]

[Text] During recent years a great number of monographs and scientific works have been published in our country in the field of hydrometeorology. For the most part they are addressed to specialists. However, many readers who are not specialists in this field would like to know what the channels of our rivers were like thousands of years ago, what is responsible for the marked changes in weather and how our climate and environment would change in connection with the proposed southward shifting of part of the runoff of northern and Siberian rivers. And they would like to obtain answers to many other questions.

The reader has been waiting for interesting popular science books to be written on this subject. For the time being, unfortunately, there are very few such books, particularly in the field of hydrology. Therefore, the publication of the book by I. V. Popov, entitled ZAGADKI RECHNOGO RUSLA (Mysteries of the River Channel), must be welcomed.

At the present time the problems related to study of deformations of river channels and floodplains are extremely timely. Very frequently they determine the fate of many structures in the river channel and on the floodplain. We can cite many examples when a river has destroyed water intake structures or when a river has left its channel and has washed away foundations, the supports of power transmission lines, pumping stations and other structures on pipelines. And the reason is always the same -- the engineers planning these structures did not take into account the course of the channel process or river channel deformations.

This book is devoted to an exposition of the principles of the hydromorphological theory of the channel process, in whose formulation the author of this book participated. At the same time it is a sort of caution to designers and builders, reminding them of the need to take possible channel changes into account.

The book consists of two parts. The first is called "Short Stories About the River Channel." These are stories about what man did not make provision for and what happened because of this. Their author is a well-known scientist in the field of investigation of the morphology of river channels and the development of methods for their rational use. He and his students on many occasions have gone out into different regions in the USSR in order to make on-site evaluations of the complex nature of the channel process and to observe the further course of river channel deformation.

The second part is entitled "What is the Nature of the Hydromorphological Theory of the Channel Process." He begins this with the question: "How Old are Our Rivers?" In reading this section, the reader gets an idea on how to determine the age of a river channel, about the relationship between age and glaciation and recent deformations.

Before explaining to the reader the essence of the hydromorphological theory of channel processes, the author tells how it is possible to determine the age of a river, about reversible and irreversible deformations of the river channel, runoff of sediments, laws of motion of suspended and bottom sediments, types of channel process, etc. The knowledge obtained on this and other matters will assist the reader in comprehending the hydromorphological theory, its practical applications.

In conclusion the author expresses the opinion that regional specialists, school children and students at technical schools and colleges can participate in and contribute much to channel investigations. The information which they collect on channel deformations can find practical use.

We hope that in the immediate future professional hydrologists will write many interesting popular science books.

SEVENTIETH BIRTHDAY OF KONSTANTIN PETROVICH VOSKRESENSKIY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 p 121

[Article by A. A. Sokolov, I. A. Shiklomanov, V. I. Babkin, V. S. Vuglinskiy, B. M. Dobroumov and A. V. Karaushev]

[Text] Doctor of Geographical Sciences Konstantin Petrovich Voskresenskiy, Professor and Meritorious Worker in Science and Technology RSFSR, an outstanding Soviet scientist, marked his 70th birthday and the 50th anniversary of his scientific-productive work on 12 November.

The name of K. P. Voskresenskiy is associated with the development of one of the fundamental directions in modern hydrology -- the study of runoff and the water balance.

K. P. Voskresenskiy began his activity in the field of hydrology with the study of channel processes at the State Hydrological Institute. During 1931-1936 he actively participated in the work of the Amudar'ya Channel Station, in investigations of the channel regime of the Volga, Oka, the rivers of the Caucasus and the Far East. During the prewar period (1937-1941) K. P. Voskresenskiy carried out a series of investigations in the field of hydrological forecasts. He participated in the development of the scientific principles of a method for predicting the water regime of large rivers in the USSR.

During the period of the Great Fatherland War Konstantin Petrovich was in the Soviet Army; he participated in the battles at Leningrad and was seriously wounded. Beginning in 1945, and for 25 years, he headed the key scientific subdivision of the State Hydrological Institute -- the Water Balance and Runoff Computation Division. Beginning with that time the scientific interests of Konstantin Petrovich were closely associated with solution of the central problems in hydrological engineering -- the development of new, and improvement of existing, methods for computing runoff during construction planning. The results of his investigations in this field were completed by the preparation of three scientific monographs in 1948-1953. In 1956 he published a monograph entitled GIDROLOGICHESKIYE RASCHETY PRI PROYEKTIROVANII SOORUZHENIY NA MALYKH REKAKH, RUCH'YAKH I VREMENNYKH VODOTOKAKH (Hydrological Computations in the Planning of Structures on Small Rivers, Streams and Intermittent Watercourses), and in 1955-1964, under the direction of and with the direct participation of K. P. Voskresenskiy, monographs were prepared on the water resources of regions of exploitation of the virgin and idle lands. During 1959-1968 Konstantin Petrovich carried out major investigations for evaluating the water resources of the territory of the USSR, completing the compilation and publication of a monograph entitled NORMA I IZMENCHIVOST' GODOVOGO STOKA REK SOVETSKOGO SOYUZA (Norms and Variability of the Annual Runoff of Rivers in the Soviet Union). The data cited in this monograph were used extensively in formulating the General Plan for the Multisided Use of the Water Resources of the USSR in 1961-1980 and for evaluating the water resources in administrative regions, economic regions and union republics of the USSR. Konstantin Petrovich Voskresenskiy for this work was awarded the academic degree of Doctor of Geographical Sciences. During the years 1966-1972, with the direct participation of K. P. Voskresenskiy, important norm-setting documents were prepared: UKAZANIYA PO OPREDELENIYU RASCHETNYKH VELICHIN GODOVOGO STOKA REK I YEGO VNUTRIGODOVOGO RASPREDELENIYA (Instructions on Determining the Computed Levels of Annual Runoff of Rivers and its Intra-annual Distribution)(SN-371-67) and UKAZANIYA PO OPREDELENIYU RASCHETNYKH GIDROLOGICHESKIKH KHARAKTERISTIK (Instructions on Determining Computed Hydrological Characteristics)(SN 435-72), mandatory for use in construction planning.

Konstantin Petrovich did much important work in studying the water balance of the Soviet Union and the earth as a whole. He participated in the preparation of unique monographs: VODNYYE RESURSY I VODNYY BALANS TERRITORII SOVETSKOGO SOYUZA (Water Resources and Water Balance of the Territory of the Soviet

Union) and MIROVOY VODNYY BALANS I VODNYYE RESURSY ZEMLI (World Water Balance and Water Resources of the Earth). Konstantin Petrovich was the author of more than 100 scientific studies on various aspects of hydrology. In addition to his scientific activity, he does much teaching.

Konstantin Petrovich enjoys extensive fame among the professional hydrologists of our country and abroad.

K. P. Voskresenskiy has been awarded the Order of the Red Star and medals. Distinguishing characteristics of Konstantin Petrovich, this great professional hydrologist, are his high dedication to science, exceptional modesty and profound commitment to hydrology.

Konstantin Petrovich has reached his 70th birthday at the height of his creative powers, full of plans for the future. We wish Konstantin Petrovich good health and further successes in this productive scientific activity.

SEVENTY-FIFTH BIRTHDAY OF ARON MARKOVICH GINDIN

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 p 122

[Article by V. N. Zakharov]

[Text] Aron Markovich Gindin, member of the State Committee on Science and Technology, Hero of Socialist Labor, winner of the Lenin and State Prizes, was honored on 29 September 1978 at the USSR State Committee on Science and Technology in connection with the 75th anniversary of his birth.

The solemn session was opened by the chairman of the State Committee on Science and Technology Academician V. A. Kirillin. In his introductory words he characterized the many years and productive activity of A. M. Gindin in hydroelectric power construction and the administration of the State Committee on Science and Technology, warmly congratulated Gindin and wished him good health and great success.

Gandin was warmly welcomed by the workers of the Bratsk Hydroelectric Power Station, at which A. M. Gandin worked from 1955 until it was put into commercial exploitation in 1967, and also by representatives of a number of state committees, ministries, scientific institutes and other organizations.

V. I. Korzun spoke in the name of the USSR State Committee on Hydrometeorology and Environmental Monitoring. He noted the close interaction between Gandin and the State Hydrometeorological Committee and its institutes on the problems relating to the complex use of water resources, the formulation of scientific and technical principles and the introduction of a progressive system for observing, monitoring and evaluating the state of the environment.

Among the numerous addresses and congratulations there was addresses from the USSR State Committee on Hydrometeorology, State Hydrological Institute, State Oceanographic Institute and also other scientific research institutes of the State Committee on Hydrometeorology and Environmental Monitoring.

CONFERENCES, MEETINGS AND SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 122-125

[Article by V. V. Kostarev, G. P. Beryulev and N. P. Bessonov]

[Text] The Fifth All-Union Conference on Radiometeorology was held in Kishinev during the period 15-19 May 1978. The conference was attended by about 160 representatives of 43 organizations in the Soviet Union. Specialists from CzSSR and the GDR were present as conference guests.

At the conference there were representatives of 14 organizations of the State Committee on Hydrometeorology, six institutes of the USSR Academy of Sciences, 9 colleges of the Ministry of Higher and Intermediate Education USSR, and 11 organizations of industrial ministries and departments.

A total of 12 reviews and 93 reports and communications were presented in two sections at the three sessions.

The reports demonstrated the results of scientific research work in the field of new applications of radiophysical equipment and methods in meteorology, in the creation of specialized apparatus, and accumulation of experience in the processing, dissemination and use of the collected information. At the conference great attention was devoted to investigations of clouds and precipitation using radiometric apparatus, laser and acoustic sounding, and also radiometric determination of the profiles of meteorological elements in the lower troposphere.

During the time which has elapsed since the Fourth All-Union Conference, held in 1975, definite successes have been achieved in radar measurements of precipitation, in the detection and short-range forecasting of dangerous phenomena, in the study of mesoscale flows in clouds, and in improvement in radar servicing of hail protection services. At the same time new apparatus has been created and existing equipment has been improved for the processing, analysis and dissemination of data obtained using radars. A new generation of meteorological radars is being introduced in the subdivisions of the antihail service.

Also being developed are new principles of radiophysical methods for studying the structure, dynamics and electric characteristics of clouds. There has been improvement in the interpretation of radar measurements and also observations of the geometrical and microphysical characteristics of clouds and fogs. Definite possibilities for measuring the liquid water content of clouds and the intensity of precipitation during synchronous radar and radiometric observations have been established.

Theoretical and experimental investigations have made it possible to estimate the ranges of wavelengths promising for radiometric measurements of atmospheric parameters. Specialists have also developed principles and methods for radioacoustic sounding of the atmosphere. Theoretical and experimental studies have been made of the possibilities of interpreting the results.

A conference resolution noted the generally successful development of work on problems relating to radiometeorology, broadening of interest and participation of scientific cadres of the State Committee on Hydrometeorology and other organizations in carrying out investigations, developing apparatus and applying measurements and observations. At the same time, the resolution noted:

-- the need for intensification of work on the metrological support of remote, radar, radiometric, lidar and acoustic measurements;
-- the desirability of creating specialized polygons outfitted with instruments and equipment for the reliable interpretation of data from remote measurements;
-- the timeliness of developing methods and apparatus for the multisided analysis of information from the network of meteorological radars on the basis of use of modern computers;
-- the need for a deeper study of the needs of users for information obtained by remote methods for routine and scientific research purposes. Particular attention must be devoted to a shortening of the time required for practical introduction of the developed radiophysical instruments and methods.

The conference recommended that particular attention be given to:
-- development and improvement of means for the detection and identification of dangerous weather phenomena for the purpose of short-range forecasting and artificial modification;
-- creation of remote methods for determining the profile of meteorological elements to an altitude of 2-3 km for the servicing of aviation and the prediction of atmospheric contamination;
-- realization of a measuring system, including meteorological radars and small electronic computers, for storm warnings and measurements of precipitation over great areas;
-- development of methods for determining gas components in the atmosphere (carbon dioxide, water vapor, nitrogen) applicable to environmental problems;
-- broadening of work favoring the use of radiometeorological methods in scientific-research problems in atmospheric physics, such as study of clouds and precipitation, air currents in clouds, clear-sky turbulence and prediction of hail activity.

In the field of investigation of the influence of meteorological processes on radio wave propagation the conference deems the following desirable:

-- theoretical and experimental study of the mechanism of radiation transfer, taking into account the influence of the underlying surface;
-- continuation of work on investigation of the spatial distribution of the refractive index and absorbing properties of the troposphere;
-- development of statistically supported models of the atmosphere and the phenomena transpiring in it applicable to determination of the influence of meteorological conditions on radio wave propagation;
-- study of the structure of precipitation fields in different climatic zones for problems involved in maintaining radio communication via space vehicles.

V. V. Kostarev and G. P. Beryulev

In June 1978 the State Committee on Hydrometeorology held an interdepartmental conference on problems relating to investigations in the field of applied climatology and improvement in the system for supplying the national economy with data on the climate of the USSR.

The conference was opened by S. K. Cherkavskiy, head of the Hydrometeorological Services Division of the State Committee on Hydrometeorology. In an introductory speech he noted that recently there has been a continuous increase in the requirements on climatic information both with respect to direct data on climate over a long period of years and with respect to the methods for determining the climatic parameters with different frequencies of recurrence and climatic resources on the basis of the characteristics of an oblast, kray and republic.

This phenomenon is caused by a number of circumstances, the most important of which are:
-- development of industrial, transportation, agricultural and urban construction in regions of Siberia and the Far East, Central Asia and Kazakhstan, where climatic conditions exert a substantial influence on construction work, operation of transportation, agricultural production and conditions for the work and the life of the people;
-- use of new types of construction of structures, including high (up to 500 m) structures, new construction materials;
-- an increase in the technical level in construction planning and a more complete allowance for climatic factors for the purpose of increasing the reliability of operation of structures and reducing their cost;
-- increasing requirements on the creation of comfort of the environment of cities by means of a more complete allowance for the peculiarities of climate in their building;
-- a more complete allowance for the resources of heat, moisture, snow and wind power resources in the national economy (agriculture, power, etc.);
-- development of measures for preserving the environment;
-- improvement of national and departmental standards associated with climatic conditions (expenditure of heat, special clothing, etc.).

The problems involved in climate, its natural variations and changes as a result of anthropogenic factors, have attracted the attention of many international organizations. Profound scientific investigations of this problem must be carried out.

The USSR State Committee on Hydrometeorology and Environmental Monitoring is proposing that an inventory (reference manual) on the climate of the USSR be prepared.

The first deputy chairman of the State Committee on Hydrometeorology Yu. S. Sedunov noted the usefulness of the conference, the materials of which will enable us to understand how the national economy is supplied with data on climate. In this connection the Main Geophysical Observatory must determine what must be done in order to improve climatic servicing to users and give solutions for the following problems. Are there enough observation points for covering the territory in climatic respects? What should be the accuracy of observations, the usefulness of the collected data, the completeness of the set of observed parameters? To what degree do the published generalizations on the climate of the country satisfy users? What must be done in order to ensure specialized climatic servicing of different branches of the national economy?

In principle, such servicing must be carried out on the basis of a data bank registered on technical carriers. A "question-response" system must be created for routine use.

At the present time the problems related directly to climatic data are tied in to the problems involved in contamination of the environment and climatic change.

It is also necessary to bring into order the system of scientific developments, devoting particular attention to trends in small regions, to systematize data for foreign territories, to increase the number of climatic parameters and their complexes.

Ye. P. Borisenkov, director of the Main Geophysical Observatory, presented a report entitled "Physical Principles of Climate, Status of the Theory of Investigations in the Field of Applied Climatology and Prospects for its Development," in which he gave a brief characterization of the USSR national program for study of the physical principles of climate and its change, and also reported on the status of investigations in the field of applied climatology.

A report entitled "Status and Prospects of Servicing the National Economy with Data on Climate, Fundamental Principles for Conducting an Inventory of the Climate of the USSR" was presented by the deputy chief of the Administration of Hydrometeorological Servicing of the State Committee on Hydrometeorology, G. G. Sivoplyas.

The speaker told about the present status of servicing the different branches of the national economy with climatic data; he noted the shortcomings in this work and reported on the prospects for the future.

The conference also heard a report on a draft of the POLOZHENIYA O KADASTRE PO KLIMATU SSSR (Principles of a Climatic Inventory of the USSR) (handbook on the climate of the USSR).

It is proposed that the inventory will be intended for supplying interested organizations, enterprises and institutes with information on the climatic resources (including heliopower and wind power) and the climatic parameters in the territory of the USSR, which in their makeup, accuracy and time of dissemination must correspond to different requirements of the national economy.

A representative of the Central Scientific Research Institute of Construction Designs of the USSR GOSSTROY A. A. Bat', in a report entitled "Requirements for Climatic Data for Supporting Construction Designs," reported on the leading requirements for climatic information on snow and wind loads.

The chief engineer of the Main Scientific Research Project of the USSR Power Ministry L. I. Kudoyarov outlined the requirements on climatic data for the planning of power structures and enterprises (including the energy resources of the sun), noting the need for preparing the complex characteristics of climate.

M. M. Chernavskaya (Central Scientific Research and Planning Institute of City Construction) formulated requirements on the content and form of representation of climatic data for planning the built-up areas of cities and populated places.

N. V. Obolenskiy, representing the Institute of Engineering Physics at the conference, reported on the requirements on computed climatic parameters used in architectural-construction planning.

A series of proposals on the development of the nomenclature of climatic indices for the classification of dwellings was expressed by the chairman of the Central Scientific Research and Planning Institute of Standard and Experimental Planning of Dwellings, V. K. Litskevich.

The scientific basis for creating a specialized medical-meteorological information and forecasting system was presented in the proposals of V. F. Ovcharova, representing the Central Scientific Research Institute of Curortology and Physical Therapy.

D. I. Shashko (State Scientific Research Institute of Land Resources) dealt with the problems involved in agrometeorological support of development of work on the problem of use of land resources.

Ye. P. Nikiforov told of investigations of glaze and glaze-wind loads on electric lines, which are carried out at the All-Union Scientific Research Institute of Electric Power.

The conference make known certain successes in the development of research in the field of applied climatology and the introduction of the results of these investigations in the practice of construction designing, long-term planning and also in the development of measures for safeguarding the environment against contamination. However, it was noted that presently available climatic information does not fully correspond to the imposed requirements. Some types of observations have not been developed: UV radiation, vertical distribution of individual meteorological elements in the lower part of the boundary layer, heat balance components under urban conditions.

The following do not meet the practical requirements of accuracy in measuring some meteorological elements: glaze-rime deposits, wind speed.

No system has been fully developed for the transmission of climatic information plotted on a technical carrier to users.

In order to improve the servicing of the national economy with climatic information the conference called upon the USSR State Committee on Hydrometeorology and Environmental Monitoring with the following requests:
-- in the plan of scientific research work of the State Committee on Hydrometeorology, make provision for carrying out investigations for improving existing and developing new methods for computing climatic parameters for construction planning when there is an inadequacy or absence of observations, including methods for computing dangerous and especially dangerous meteorological phenomena which rarely recur;
-- take measures for increasing the accuracy in measuring glaze and rime deposits and wind velocity;
-- in the plans for development of the meteorological network, make provision for the organization of observations of UV radiation, especially in regions of new industrial construction and the building up of new cities.

The conference also called on the USSR Gosstroy to examine the problem of improving the system for the development and refinement of standard documents containing climatic characteristics and include work on refining requirements on climatic information and improving existing methods for computing climatic parameters in construction planning in the scientific research institutes of the interested ministries and departments.

NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 p 125

[Article by B. I. Silkin]

[Text] As reported in SCIENCE (Vol 198, No 4315, pp 387-430, 1977), during the brief time elapsing since the discovery of large annular oceanic currents the number of such systems which have become known to science in the northeastern part of the Atlantic Ocean has exceeded ten. The basis for their existence is the Gulf Stream, which in passing by Cape Hatteras (United States), is deflected from the shores of North America and begins to meander, that is, form looplike curvatures.

Some of these "loops" are detached from the main channel of the Gulf Stream and become independent annular currents. The velocity of water movement in them attains high values, in individual cases up to 4 km/hour. The diameter of such rings is 150-300 km. The water masses occupied by them extend almost to the ocean floor, here having a depth of about 2,500-3,500 m.

It has now been established that the "rings," separating from the Gulf Stream from its southern side, differ from the surrounding warm waters of the Sargasso Sea in that at their center there is a nucleus with a relatively low temperature. On the other hand, those same "rings" which are separated from the northern side of the Gulf Stream carry warm "nuclei" at their center.

An annular current, having a warm "nucleus," is usually displaced in a WSW direction with a velocity up to 5 km/day. The "lifetime" of such an individual ring is somewhat less than a year, at the end of which this water mass, again reaching Cape Hatteras, pours into the Gulf Stream.

The direction of annular currents with a cold center for the most part is southwesterly and the velocity does not exceed 3 km/day. The place of their disappearance is along the eastern coast of the Florida Peninsula and the lifetime is two or three times greater.

Very recently, this sort of system has been discovered in other parts of the ocean. For example, the oceanologists of Japan are investigating them in the region of the Kuroshio Current, assuming that they must have an effect on the biological communities in the annular currents are extremely unusual in comparison with the remaining regions of the ocean.

The circumpolar current, moving around the Antarctic continent, also, it was found, generates annular cold independent systems. However, evidently, their dimensions and velocity are smaller than those observed near the Gulf Stream. For example, the annular current discovered to the south of Cape Horn has a diameter a little more than 100 km and a velocity of rotational motion of about 1.1 km/hour. Specialists are postulating that this is associated with the greater velocity of the Gulf Stream itself in comparison with the Circumpolar Current.

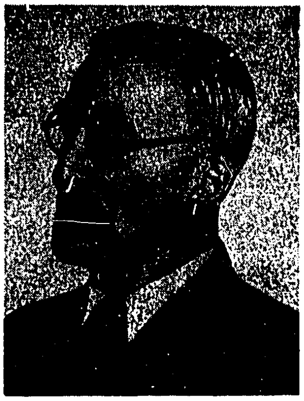
The study of annular currents, obviously characteristic of all regions of the world ocean where powerful flows of water masses are present, is of great theoretical and practical importance.

BIOGRAPHICAL NOTES ON MIKHAIL ANDREYEVICH VELIKANOV (1879-1964)

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 pp 126-128

[Article by Ye. G. Popov]

[Text] This year marks the 100th anniversary of the birth of the outstanding scientist Mikhail Andreyevich Velikanov, one of the founders of Soviet hydrology.



The name of Professor Velikanov stands in the ranks of the leading hydrologists of the world and is inseparably associated with the forming and developing of hydrology of the land as one of the geographical-geophysical sciences, destined not only for learning the general laws of the existence, distribution, circulation and regime of different forms of natural waters of the land, but also to solve many vitally important engineering and national economic problems relating to evaluation and use of water resources, hydraulic construction, irrigation, water transportation and protection against dangerous water phenomena. Five editions of his book GIDROLOGIYA SUSHI (Hydrology of the Land) (1925, 1932, 1937, 1948 and 1965) were a fundamental contribution to a systematizing of knowledge and scientific methods in hydrology. These books were used for many years in teaching and learning in Soviet hydrology.

A brilliant theoretician and lecturer, Mikhail Andreyevich Velikanov made a major contribution to formulation of a series of very important problems in hydrology and the development of its individual branches. His investigations were characterized by a combination of a profound physical analysis of complex natural processes and their mathematical description with the execution of laboratory experiments, with the implementation of the necessary field observations and experimental work. His range of scientific interests was also extremely broad: from the problems involved in the continental cycling of moisture and the water balance within the limits of a basin to the dynamics of channel flows; from the laws of formation of high-water runoff to channel processes and the theory of movement of sediments in rivers. A recognition of the great scientific services of Mikhail Andreyevich Velikanov was his election as a Corresponding Member USSR Academy of Sciences and award of the honorary title of "Meritorious Worker in Science and Technology RSFSR."

Mikhail Andreyevich Velikanov was born on 22 January 1879 in Kazan', the son of an engineer. He studied there in the gymnasium. Upon graduation he entered the Institute of Transportation Engineers in Peterburg, from which he graduated in 1903. He enters, therefore, into the ranks of those Russian engineers (V. G. Glushkov, N. M. Dolgov, Ye. V. Bliznyak, D. I. Kochergin, N. S. Lelyavskiy, V. M. Lokhtin and others), who, devoting themselves to the study of rivers and their regimes, processes of the formation of surface runoff and channel processes, laid the basis for a relatively young science -- hydrology of the land.

The work activity of M. A. Velikanov after graduation from the institute began in Siberia, where over a period of almost 10 years (from 1903 to 1912) he made studies of Siberian rivers and devoted half this time to a study of the Yenisey. During the period 1913-1916 he carried out hydrographic investigations of the Severnaya Dvina, Sukhona, Zapadnyy Bug, Berezina and Volga, continuing to study the laws of channel processes and the formation of channels in direct relationship to the dynamics of water flows. In 1917 he began his teaching activity at higher educational institutes. First this was at the Tomsk Technological Institute, and in 1920, at Omsk, at the Siberian Agricultural Institute. There he was named a professor and was approved for that title.

In 1921 M. A. Velikanov moved to Moscow, where he worked in the GOSPLAN and in the Council of the Higher Technical Committee of the People's Commissariat of Transportation and also presented lectures on hydraulics and hydrology at the Moscow Land Surveying Institute (1921) and at the Moscow Higher Technical School (1922-1929). Between 1930 and 1941 he headed the Department of Hydrology of the Land at the Moscow Hydrometeorological Institute. For many years M. A. Velikanov worked at the Power Institute USSR Academy of Sciences. There he created (1935) a laboratory of physical hydrodynamics and headed it. During the post-war years he reorganized this laboratory into a laboratory for the study of channel processes. Continuing his teaching activity, Mikhail Andreyevich in 1945 organized the training of specialists in the physics of channel flows at Moscow State University.

The multisided scientific activity of Mikail Andreyevich Velikanov was closely related to the State Hydrological Institute and other institutes of the Hydrometeorological Service. He was an active participant in the first two hydrological congresses held by the State Hydrological Institute in 1924 and 1928. His ideas and points of view on the ways for development of hydrology and methods for studying the processes of formation of runoff and other hydrological processes found reflection in the resolutions of these congresses and played an important role in the development of hydrometeorological observations, in creating runoff stations as field experimental bases for study of the physical laws controlling hydrological processes under the conditions of a specific physiographic environment. Being a scientist of the theoretical-experimental school, Velikanov insisted on the need for "transforming hydrology from a descriptive into a physical science, otherwise, a part of geophysics," emphasizing the danger of excessive attention as a strictly geographical science or any strictly statistical direction in the development of hydrology. His theoretical studies on the problems of formation of high-water runoff, the dynamics of channel flows and the movement of sediments indicated the fertility of his ideas and their practical significance became more obvious with the appearance of electronic computers, making it possible to realize many of those theoretical proposals which up to that time seemed virtually impossible. Over a period of a number of years during the post-war period M. A. Velikanov worked in a second position at the Central Institute of Forecasts, being engaged in the training of graduate students and being an active member of the Scientific Council of this institute. Here, in particular, he was engaged in solution of the important hydrodynamic problem of computing unsteady movement of water under conditions of mutual backing up of waters when two watercourses come together.

Not long before his death Mikhail Andreyevich moved from Moscow to near Leningrad at the Main Experimental Base of the Main Hydrological Institute with the intention of carrying out there a series of new investigations involving the modeling of channel flows and processes occurring in them. There he died on 30 April 1964 and was buried in a cemetery in the village of Il'ichevo.

The multisided scientific heritage of M. A. Velikanov is very great. It is surprising in the breadth and depth of his understanding of natural processes, in the clarity of his formulation of fundamental problems in the development of hydrology, and his uncompromising evaluations of inadequately correct approaches to solution of complex problems and attempts presented to justify them with use of inadequate initial data. In a brief journal article there is no possibility of examining the significance of even the most important studies of M. A. Velikanov. Therefore, we will limit ourselves only to the most general comments.

In addition to the already mentioned five editions of the book GIDROLOGIYA SUSHI, serving as a study aid for many generations of students, there are other books by M. A. Velikanov which enjoy wide fame: VODNYY BALANS SUSHI

(Water Balance of the Land)(1940), DINAMIKA RUSLOVYKH POTOKOV (Dynamics of Channel Flows)(1946), DVIZHENIYE NANOSOV (Motion of Sediments)(1948), DINAMIKA RUSLOVYKH POTOKOV (T. I "STRUKTURA POTOKA," 1954, T. II "NANOSY I RUSLO," 1955) (Dynamics of Channel Flows, Vol I "Flow Structure, 1954, Vol II (Sediments and Channel, 1955), RUSLOVOY PROTSESS (Channel Process)(1958), OSHIBKI IZMERENIYA I EMPIRICHESKIYE ZAVISIMOSTI (Measurement Errors and Empirical Dependences)(1962), and also his articles devoted to a hydromechanical analysis of surface runoff and an isochronous model of formation of high waters, published, for example, in the journal GEOFIZIKA (Geophysics), No 1-2, 1931, in the journal METEOROLOGIYA I GIDROLOGIYA (Meteorology and Hydrology), No 3, 1941, and a number of other articles.

Despite all the diversity of the contribution of M. A. Velikanov to the development of hydrology of the land, the principal field of his scientific interests must nevertheless be considered the problems of the dynamics of channel flows, channel processes and the movement of sediments. His first studies (1911-1913) were devoted to these matters. He also devoted laboratory experiments to study of the turbulent structure of channel flow at the Tomsk Technological Institute, later at the Kuchinskaya Hydrological Station, and still later in the Channel Processes Laboratory USSR Academy of Sciences. These matters occupied him to the last days of his life. His published works enumerated above made a fundamental contribution to science. In particular, we should mention M. A. Velikanov's gravitational theory of the motion of suspended alluvium, which, from the point of view of physical validation, differs advantageously from the simpler (and up to now, more attractive) diffusion theory, which, however, as noted by Mikhail Andreyevich, is correct for the transport of a "weightless substance" and in principle is applicable only for extremely light suspended material. The debatable problems associated with evaluation of these two theories were broadly discussed at one time on the pages of IZVESTIYA AKADEMII NAUK SSSR (News of the USSR Academy of Sciences)(1952). It can only be regretted that even now, with the availability of electronic computers, the gravitational theory of motion of suspended sediments nevertheless has not received suitable approbation and development. We also note Velikanov's proposal of hydromorphological dependences which recently have come into use in solving the problem of scale relationships in hydraulic modeling.

With respect to the studies of M. A. Velikanov on the theory of formation of shower- or snow-induced high waters, we note that the equation derived on the basis of an isochronal model for computing the inflow of water into a channel in the form of a convolution integral was obtained by him many years before this integral under the name Duhamel integral came into broad use in linear models of the formation of high water abroad.

M. A. Velikanov was an opponent of the special segregation of statistical methods in hydrology, but at the same time he repeatedly emphasized the major role of statistics in the solution of many problems in hydrology. In particular, he examined such problems as the use of "composition" methods in establishing the distribution functions of peak high-water discharges, the stochastic structure of hydrological forecasting and allowance for its errors. One of the last of his studies was, as already noted, a book devoted to measurement errors and empirical dependences. It would be useful to republish this book.

Simultaneously with the great scientific and pedagogic work of M. A. Velikanov, as a consultant and expert he participated in the creation in our country of large water management systems, hydroelectric power, navigation and irrigation structures.

Soviet hydrologists honor the memory of Mikhail Andreyevich Velikanov. They now make extensive use of his ideas and studies in their investigations for the further development of hydrology and in solving its practical problems and will long continue to do so.

OBITUARY OF MILEYKO GEORGIY NIKITICH (1919-1978)

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 1, Jan 1979 p 128

[Article by a group of comrades]

[Text] Candidate of Geographical Sciences Mileyko Georgiy Nikitich, a senior specialist at the USSR Hydrometeorological Center, died prematurely on 6 September 1978.

Georgiy Nikitich became associated with the Division of Marine Hydrological Forecasts on the eve of its creation. In 1944, after graduating from the Hydrometeorological Institute, he was sent to the Central Institute of Forecasts, where he worked to his last day.

During his first years of work at the institute G. N. Mileyko headed a section on marine information, invested much energy and all his knowledge in order to improve the servicing of national economic organizations with marine forecasts, repeatedly participating in both organizing and carrying out marine expeditions and ice aerial reconnaissance. He worked for many years in the field of computing and predicting the distribution of water temperature and the position of the ice edge in the oceans and seas.

The scheme which he developed for predicting water temperature is used in the routine practice of the USSR Hydrometeorological Center and a number of Administrations of the Hydrometeorological Service. Recently G. N. Mileyko developed a method for computing convective heat transfer from the ocean into the atmosphere; it is used for the purpose of numerical long-range weather forecasting.

G. N. Mileyko was one of the authors of a code for shore hydrometeorological observations at sea stations and posts (KN-02, and also the codes KN-05 and KN-06) and manuals on the use of aerial methods in oceanography. In 1977 he published an atlas of the mean long-term characteristics of the temperature regime of waters in the North Atlantic. The director of this work was G. N. Mileyko. He was one of the initiators in organizing the guidance of ships on the most advantageous navigation routes in the seas and oceans.

Georgiy Nikitich Mileyko combined his many years of experience in the field of marine forecasts and research work with routine servicing, methodological work and the teaching of young specialists in the division. He carried out all work with great care and on time. He taught these things to youth.

The memory of Georgiy Nikitich Mileyko will forever remain in our hearts.

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